

ENVIRONMENTAL FACTORS INFLUENCING THE GROWTH AND YIELD OF RAMBUTAN AND CUPUACU

Rural Industries Research and Development Corporation
RIRDC Final Report; Project DNT - 10 A

Northern Territory Department of Primary Industry and Fisheries

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Executive Summary

Rambutan (*Nephelium lappaceum*) a relative of lychee is native to the wet tropics of SE Asia. The crop was introduced into Australia in the 1970's and has been grown commercially in the Northern Territory (NT) since the early 1980's. Cupuacu (*Theobroma grandiflorum*) is a relative of Cocoa and is native to Brazil. The fermented seed reportedly can be used for the production of a chocolate substitute. Cupuacu is a new crop to Australia and little information exists on its ability to grow in the wet/dry tropics.

The aim of the project was twofold. First, to investigate in detail the growth and yield of rambutan in relation to environmental conditions with particular reference to temperature and soil moisture management. Secondly, to provide preliminary information on the growth, phenology and yield of Cupuacu grown in the NT.

This report consists of two parts. Part One deals with the detailed work carried out on rambutan and Part Two reports on the preliminary growth and phenology studies carried out on Cupuacu.

Rambutan

The climate in northern Australia, particularly the Northern Territory (NT) where a small commercial rambutan industry exists (Ngo 1996), is different from the plants native environment in SE Asia. In SE Asia annual rainfall is high and evenly distributed, humidity is high, evaporation is low and average minimum temperatures are generally greater than 18°C. In the wet/dry tropics of northern Australia there is seasonal drought, during which humidity is low, evaporation is high and night temperatures have been recorded as low as 8°C. Wet season conditions approximate those in SE Asia.

The project aimed to gain a better understanding of how the perceived climatic limitations of the NT environment affected flowering and potential productivity. An improved understanding of rambutan growth, floral phenology and tree water requirements were required to allow improved crop management strategies to be developed. The research strategy included;

- monitoring of tree phenology over three years in existing commercial and research plantings;
- detailed investigation of leaf net CO₂ assimilation in response to differing irrigation regimes in potted plants and nil irrigation in mature trees;
- detailed root distribution studies;
- use of controlled environment glasshouse facilities to determine the vegetative response to day/night and root temperatures;
- investigation of pre-flowering water deficit to promote earlier flowering;
- calculation of water requirements;
- development of practical irrigation management recommendations for growers.

The findings showed that in the NT rambutans are distinctly seasonal with flowering occurring in June/July and harvesting occurring from November to January with the peak

harvest in early December. Following harvest and a light tip pruning, there are four major vegetative flushes until the onset of cooler nights in mid May.

Anecdotal evidence indicated that rambutans in the NT suffer severe leaf drop following ten days of nil irrigation. Detailed investigation of leaf net CO₂ assimilation in response to differing irrigation regimes in potted plants and nil irrigation in mature trees showed that there is a rapid decline in leaf water potential (Ψ_L) and CO₂ assimilation (A) following the cessation of irrigation. In potted plants this decline was observed on the second day whereas in mature trees a slower but significant decline occurred from day three following removal of irrigation. Soil moisture monitoring data suggested that rambutan is a shallow rooted species.

Root distribution sampling on mature trees showed that 80 % of the root system is in the top 15 cm of the soil surface and within the dripline of the tree. This has major implications for irrigation and perhaps fertiliser management of trees which are grown in a wet/dry tropical environment. Controlled environment temperature studies revealed that rambutan vegetative growth ceases under cool day/night conditions (22°/14°C) and is only marginally better at the warm day cool night temperature regime (32°/14°C). The study showed that cool nights below 22°C are likely to reduce growth even when day temperatures are high. The tropical adaptation of this species has been confirmed.

The response of leaf gas exchange to vapour pressure deficit (VPD) indicates that the tree can assimilate CO₂ over a wide range of humidities. This is surprising considering the tree's origin in the wet tropics. But, it does explain why the trees have grown well in the wet/dry tropics of the NT where low humidity is experienced during the dry season. Pre-flowering drought is reported to trigger flowering in the rambutans native environment. In the NT the onset of cool nights appears to be the dominant flowering trigger. Work on the effect of pre-flowering drought suggests that it can help synchronise flowering but, does not induce flowering, to occur earlier than is possible when trees are irrigated.

This study allowed the water requirements of rambutan to be assessed at different growth stages. Water use is highest during fruit filling and lowest in the pre-flowering vegetative phase. A practical irrigation guide has been designed for growers which calculates water requirements based on tree canopy cover and evaporation replacement factors for the various growth phases. The wet/dry tropics of northern Australia are more extreme than the plant's native environment. However, with the aid of careful irrigation management and limiting the range of production to areas with minimal periods of low temperature, rambutan production can occur successfully.

Cupuacu

Cupuacu is a relative of cocoa and is commonly used in Brazil for the production of juice, nectar and jams from the considerable mass of pulp found around the seeds. The fruits, commonly called pods, are generally larger than those of cocoa and rounder in shape. A number of publications, from Brazil, suggest that the seeds can be used to make a chocolate like product called "cupulate". The cupulate product is low in caffeine and theobromine, two stimulants which are found in chocolate, and hence may be useful for creating a "health food" product. Cupuacu also lends itself to mechanical harvesting as the pods drop to the ground when ripe, unlike cocoa which needs to be harvested by hand. The combination of novel

product possibility and applicability of mechanical harvesting suggests that Cupuacu may have potential as a new crop for the tropical north of Australia.

Seed of cupuacu were introduced into the NT in 1991. In 1992, 130 established seedlings were planted at the Department of Primary Industry and Fisheries, Coastal Plains Research Station. Tree growth, phenology and yield were monitored in conjunction with environmental parameters. The aim of the study was to determine whether cupuacu would grow and yield in the wet/dry tropics of the Northern Territory.

Cupuacu established and grew well under irrigation. Its performance was difficult to compare with other plantings as there is no publicly available data on growth and yield of Cupuacu in its native or any other environment. The dry bean yield of four year old trees was 430 kg/ha. This yield is low when compared to similar aged cocoa trees where the dry bean yields are reported as high as 1,400 kg/ha. The low yields are thought to be partly due to the low bean recovery rate (10 %), compared to 31.5-46 % for Cocoa. The direct comparison of Cupuacu and Cocoa yield data may not be appropriate as observations suggest that Cocoa growth rates are appreciably higher than Cupuacu.

The commercial potential of Cupuacu needs to be thoroughly evaluated prior to further agronomic studies being undertaken. The plot at CPRS should be used for further yield monitoring and trial fermentation of seed so that the cupulate product can be evaluated by commercial chocolate manufacturers. Ideally this work should be carried out in conjunction with a commercial partner. Evaluation of the pulp as a flavouring in nectars and juices may increase the economic viability of the crop if the "cupulate" is found to be commercially acceptable.

Acknowledgments

As the project leader I would like to take this opportunity to thank the project cooperators Dr. Derek Eamus, School of Biological Sciences, Northern Territory University, Darwin and Dr. Christopher Menzel, Maroochy Horticulture Research Station, Queensland Department of Primary Industry, and their organisations for their technical and financial support. Despite their considerable assistance with the project any errors or misinterpretation of data are solely the responsibility of the project leader.

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Part One

Environmental Factors Influencing the Growth and Yield of
Rambutan (*Nephelium lappaceum* L.) in the Wet/Dry Tropics of
Northern Australia.

1.0 Introduction

The rambutan (*Nephelium lappaceum* L.) is native to West Malaysia and the island of Sumatra in Indonesia (Watson, 1984). The tropical evergreen tree is a member of the Sapindaceae family and hence related to longans and lychee. The fruit is used chiefly as a fresh dessert fruit. Industrial uses of the fruit for the production of jams, jellies and canned products have occurred (USDA, 1979).

The crop is grown in a number of locations outside its natural distribution including the greater part of South East Asia, Central America, Africa and northern Australia. In Northern Eastern Australia, cultivars so far screened are only suitable for coastal areas north of Ingham (18° 50' south, Watson, 1988). In the Northern Territory plantings are restricted to north of 14° S. Areas further south than those described are not suitable due to the likelihood of experiencing mean minimum temperatures below 15°C.

The native environment of the rambutan is characterised by high rainfall (evenly distributed), high humidity, low evaporation rates and average minimum temperatures above 20°C (Table 1).

Table 1. Environmental conditions in SE Asia and Darwin where rambutans are successfully grown.

Location	Max. monthly Temp (°C)	Min. monthly Temp (°C)	Av. yearly rainfall (mm)	Av. yearly Evap (mm)	Months moisture deficit ⁺
Jakarta* (Indonesia)	32.9	22.9	1823	1036	4
Singapore*	31.6	22.8	2161	1610	0
Alor Setar* (Malaysia)	34.4	21.7	2197	1760	4
Darwin [#]	33.1	19.3	1665	2685	8

* ASEAN, (1982); [#] Bureau of Meteorology, (1993); ⁺ Number of months evaporation exceeds rainfall.

The major limitations to growth in northern Australia and the higher latitude areas are environmental and include: drought, low temperature and high vapour pressure deficit (VPD). The lack of available soil water has largely been overcome by the use of irrigation. However, the amount of water required and timing of application in relation to the trees phenology is not known.

Evaporative demand, particularly during the flowering months of June to August, is high in the wet-dry tropics. The effect of these conditions on flowering and subsequent flower viability and pollination is not known.

Low temperatures (generally below 15.0°C) are reported to cause leaf burn and leaf drop, thereby delaying or preventing flowering and fruit set. Varietal screening in North Queensland by Watson (1988) has shown varietal differences in terms of their response to low temperature. This matter needs to be further investigated in terms of selecting varieties

which are more suited to the growing conditions available or to investigate ways of ameliorating the effects of low temperature through irrigation management.

In Australia the fruit has grown in popularity and a considerable area has been planted to Rambutan. The rambutan industry is currently valued at \$2.7 M (Lim and Diczbalis, 1995) with the bulk of the crop being grown in North Queensland. The Northern Territory industry although smaller provides approximately a third of the value of the industry. In the Northern Territory, rambutan is an emerging tropical fruit crop and is profitable to grow (Ngo and Baker, 1990) with a market value in 1994 of \$800,000 (NT DPIF, 1994) with an estimated 12,000 trees planted (140-200 ha) and many yet to bear (M. Poffley, Pers. Comm. 1994). The industry has done well considering the lack of both local knowledge and scientifically documented work.

Irrigation is a necessary part of production in the wet-dry tropics. Current irrigation management in commercial orchards is ad-hoc and based on a few years of experience. There is a poor understanding of the trees water requirements by both growers and researchers. Poor irrigation management of crops can result in defoliation, poor or delayed flowering and poor fruit set and size. These factors adversely affect yield and hence the value of production. No detailed studies are available to quantify the effect of irrigation on fruit yield and quality (Lam and Tongumpai, 1987).

In the NT, the dry season (May to September) is the main period during which irrigation is required. Irrigation rates and frequency varies from orchard to orchard. However, observation of commercial irrigation practices suggest that rambutans benefit from daily applications of water. The amount required on a daily basis during the different phenological stages is still unclear. The wet season (October to April) although reliable in terms of total rainfall, is still a period in which irrigation is required due to in-season variability (Mollah, 1986).

Delayed or poor flowering is of major concern to growers in the NT, who are able to exploit a market window which exists in November - December, prior to the onset of fruit availability in Queensland. Better control of flowering through improved irrigation management would greatly facilitate income stability for growers in the NT and Queensland.

To date, the only work carried out on rambutan has been on variety selection and locality suitability studies (Watson, 1988; Hobman, 1984). There is a dearth of information on the response of the rambutan in relation to changing environmental characteristics. In Queensland the QDPI has commenced work on manipulation of flowering, first, by conducting a study of phenological patterns during the year in relation to climate, and second, by measuring starch levels in plants, which is reported to be indicative of floral induction in Lychee (Nakata and Watanabe, 1966; Menzel, *et al.* 1989).

This report documents the RIRDC funded work carried out by the NT Department of Primary Industries and Fisheries (DPIF), Northern Territory University (NTU) and Queensland Department of Primary Industry (QDPI) to ascertain the response of rambutan to environmental variables.

1.1 References

- ASEAN (1982). The ASEAN compendium of climatic statistics. ASEAN sub-committee on climatology, ASEAN committee on Science and Technology, Indonesia.
- Bureau of Meteorology (1993). Tabulation of climatic averages and extremes - Darwin. Commonwealth of Australia.
- DPIF (1991). Northern Territory Primary Industry and Fisheries Statistics 1989-90. NT Department of Primary Industry and Fisheries, Technical Bulletin No. 168.
- Hobman, F.R. (1984). Preliminary assessment of rambutan clones in Australia. Queensland Journal of Agriculture and Animal Science, Vol 41 : 115-119.
- Lam, P.F. and Tongumpai P. (1987). Pre-harvest factors affecting post-harvest quality of rambutan in Rambutan : Fruit development, post harvest physiology and marketing in ASEAN. Editor : P.F. Lam and S. Kosiyachinda. ASEAN Food Handling Bureau, Kuala Lumpur. Malaysia.
- Lim, T.K., and Diczbalis, Y. (1995). Rambutans *in*: Horticulture Australia. Morescope Publishing.
- Menzel, C.M., Rasmussen, T.S. and Simpson, D.R. (1989). Effects of temperature and leaf water stress on growth and flowering of litchi (*Litchi chinensis* Sonn.). Journal of Horticultural Science, 64:739-752.
- Mollah, W. (1986). Rainfall variability in the Katherine-Darwin Region of the Northern Territory and some implications for cropping. The Journal of the Australian Institute of Agricultural Science, 52 : 28-36.
- Nakata, S. and Watanabe, Y. (1966). Effect of photoperiod and night temperature on the flowering of *Litchie chinensis*. Botanical Gazette, 127:146-152.
- Ngo, H.T. (1996). Economic assessment of rambutan production in the Northern Territory. NT Department of Primary Industry and Fisheries. Technical Bulletin no. 251.
- Ngo, H.T. and Baker, I.W. (1990). Rambutan production in the NT Top End : An agronomic and economic evaluation. NT Department of Primary Industry and Fisheries, Technical Bulletin No. 152.
- USDA (1979). Cultivation of neglected tropical fruits with promise. Part 6. The Rambutan. US Department of Agriculture Science and Education Administration
- Watson, B.J. (1984). Rambutan (*Nephelium lappaceum*) in Tropical tree fruits for Australia. Editor : P.E. Page. Horticulture Branch, Queensland Department of Primary Industry.
- Watson, B.J. (1988). Rambutan cultivars in North Queensland. Queensland Agricultural Journal. Jan-Feb 1988.

2.0 Climatic comparisons; SE Asia and north Australia (Darwin).

Y. Diczbalis

2.1 Introduction

Rambutans are native to the Malay archipelago (Cornel 1983, Tindall 1994) and have become well distributed throughout all countries in tropical South East Asia and the humid tropics of America, Africa and Australia (van Welzen, P.C. and Verheij, E.W.M. 1991). The principle characteristics of the native environment include, high well distributed rainfall, maximum temperatures in the low 30's and high minimum temperatures (22 - 25 °C) and humid conditions through out the year.

The climate in the Top-End of the NT is different from the crops native environment as well as the environment in North Queensland. The following tables document the differences in basic environmental variables such as; mean monthly rainfall, mean monthly evaporation, mean monthly maximum temperature and minimum temperature, for Darwin (NT), South Johnstone (Qld), Jakarta (Indonesia), Singapore, Alur Setar (Malaysia) and Chanthaburi (Thailand). The climate of Alur Setar on the west coast of peninsular Malaysia is indicative of the crops native environment. Climate data for Asian sites was obtained from ASEAN (1982) whereas data for Australian sites was obtained from Bureau of Meteorology (1988).

2.2 Rainfall

Rainfall in SE Asian growing environments is generally high (> 1800 mm/year) and well distributed (Table 2). The growing environment of Chanthaburi in SE Thailand is some what different in that it experiences a distinct seasonal rainfall pattern with the bulk of the rain falling from April to October. The NT environment (Darwin) is some what similar to that of Chanthaburi in that it is distinctly seasonal with the bulk of rain falling from November to April. The Darwin environment has the lowest total rainfall of the growing areas shown. The north Queensland environment is more typical of the trees native environment in that it experiences high well distributed rainfall.

Table 2. Mean monthly rainfall for rambutan growing areas in northern Australia and SE Asia

Month	Darwin	S. Johnstone	Jakarta	Singapore	Alur Setar	Chanthaburi
Latitude	12,25 S	17,36 S	6,11 S	1,22 N	6,12 N	12,36 N
Jan	406	550	381	194	54	13
Feb	349	588	302	182	66	46
Mar	317	629	240	173	115	72
Apr	99	384	119	138	199	119
May	20	265	113	160	238	346
Jun	2	155	94	154	183	503
Jul	0	99	59	133	197	464
Aug	7	84	58	148	215	533
Sep	18	86	67	144	301	536
Oct	73	90	95	181	305	297
Nov	141	132	130	243	229	72
Dec	232	246	165	311	95	14
Total	1664	3308	1823	2161	2197	3015

2.3 Evaporation

Mean monthly daily evaporation rates (mm/day) are generally low in the tree's native environment and other SE Asian environments ranging from 2.1 to 5.8 mm/day depending on location and time of year (Table 3). Rates in north Queensland are similar and rarely exceed 6.0 mm/day whereas those in the Top-End of the NT are lowest at 6.1 mm/day in February and rise to a maximum of 8.7 mm/day in October.

Table 3. Mean monthly daily evaporation (mm/day) for rambutan growing areas in northern Australia and South East Asia

Month	Darwin	S. Johnstone	Jakarta	Singapore	Alur Setar	Chanthaburi
Latitude	12,25 S	17,36 S	6,11 S	1,22 N	6,12 N	12,36 N
Jan	6.7	5.1	2.1	4.9	4.5	5.0
Feb	6.1	4.0	2.2	5.5	5.2	4.7
Mar	6.2	4.9	2.3	5.2	5.8	4.9
Apr	7.1	3.8	2.6	4.4	5.7	4.8
May	7.3	2.8	2.7	4.2	5.3	4.0
Jun	7.2	2.9	2.8	4.1	4.9	3.7
Jul	7.4	2.9	3.2	4.3	4.7	3.4
Aug	7.7	3.4	3.4	4.4	4.9	3.4
Sep	8.4	4.8	3.6	4.4	4.5	3.5
Oct	8.7	5.5	3.5	4.3	4.5	3.9
Nov	8.2	6.0	2.9	3.6	4.2	4.7
Dec	7.2	5.6	2.7	3.7	3.7	5.2

2.4 Water Budget

The water budget (rainfall minus evaporation; mm of water) for growing areas reveals that evaporation exceeds rainfall in zero to four months of the year for native growing environments, and the moisture status becomes worse as the latitude increases eg.

Chanthaburi and Darwin where monthly evaporation exceeds rainfall for six and eight months of the year respectively (Table 4). This does not hold true for the north Queensland growing site where evaporation exceeds rainfall in only four months of the year.

Table 4. Monthly water budget (mm; rainfall - evaporation) for rambutan growing areas.

Month	Darwin	S. Johnstone	Jakarta	Singapore	Alur Setar	Chanthaburi
Latitude	12,25 S	17,36 S	6,11 S	1,22 N	6,12 N	12,36 N
Jan	198	392	316	42	-86	-142
Feb	178	476	240	28	-80	-86
Mar	125	477	169	12	-65	-80
Apr	-114	270	41	6	28	-25
May	-206	178	29	30	74	222
Jun	-214	68	10	31	36	392
Jul	-222	12	-37	4	56	362
Aug	-224	-18	-44	16	68	431
Sep	-234	-58	-41	12	166	431
Oct	-188	-75	-10	52	170	180
Nov	-105	-48	43	135	103	-69
Dec	16	78	84	200	-16	-142

2.5 Temperature

Mean maximum temperatures throughout SE Asian growing areas are in the low 30's with little variation throughout the year (Table 5). Temperatures in the Top-End of the NT are similar. The maximum temperatures in north Queensland are similar from November to February, but, are considerably lower during the remainder of the year, falling to a low of 24.3 °C in July.

The mean minimum temperatures in SE Asia are in the low 20's with little variation throughout the year. The variation increases as the latitude increases. Similar conditions exist at the Darwin recording site (Table 6). Minimum temperatures recorded during the dry season in the Darwin rural area are well below those recorded at the official Meteorological Bureau site. In north Queensland mean minimum temperatures fall to 14.4 °C in June, with six months of the year (March - October) having minimum temperatures below 20 °C. Growing conditions in northern Australia are cooler at certain times of the year than is experienced in the trees native growing environment.

Table 5. Mean monthly maximum temperature (°C) for rambutan growing areas in northern Australia and South East Asia

Month Latitude	Darwin 12,25 S	S. Johnstone 17,36 S	Jakarta 6,11 S	Singapore 1,22 N	Alur Setar 6,12 N	Chanthaburi 12,36 N
Jan	31.8	31.2	30.1	29.7	32.3	31.8
Feb	31.4	30.5	30.3	30.6	33.9	32.5
Mar	31.8	29.8	31.2	31.3	34.4	32.8
Apr	32.6	28.1	32.2	31.5	33.9	33.4
May	31.9	26.0	32.4	31.5	32.5	32.3
Jun	30.5	24.3	32.2	31.0	31.9	30.9
Jul	30.4	23.8	32.1	30.8	31.7	30.6
Aug	31.2	25.3	32.4	30.6	31.6	30.4
Sep	32.4	27.1	32.9	30.8	31.1	30.5
Oct	33.1	28.8	32.9	31.0	31.1	31.3
Nov	33.1	30.6	32.2	30.4	31.3	31.2
Dec	32.6	31.2	31.5	29.6	31.1	30.8

Table 6. Mean monthly minimum temperature (°C) for rambutan growing areas in northern Australia and South East Asia

Month Latitude	Darwin 12,25 S	S. Johnstone 17,36 S	Jakarta 6,11 S	Singapore 1,22 N	Alur Setar 6,12 N	Chanthaburi 12,36 N
Jan	24.8	22.3	23.4	22.8	21.7	19.6
Feb	24.6	22.5	23.5	23.1	22.0	21.2
Mar	24.4	21.8	23.6	23.4	22.6	22.5
Apr	23.9	20.3	24.0	23.8	23.7	23.4
May	22.1	18.3	24.0	24.1	24.1	24.0
Jun	19.9	15.3	23.3	24.0	24.0	24.3
Jul	19.3	14.4	22.9	23.7	23.6	24.0
Aug	20.6	15.3	23.0	23.6	23.6	24.0
Sep	23.1	16.5	23.3	23.5	23.5	23.6
Oct	25.0	18.5	23.7	23.4	23.3	23.0
Nov	25.3	20.5	23.8	23.3	23.0	21.7
Dec	25.2	21.7	23.6	23.0	22.5	20.0

References

- ASEAN (1982). The ASEAN compendium of climatic statistics. ASEAN sub-committee on climatology, ASEAN committee on Science and Technology, Indonesia
- Bureau of Meteorology (1988). Climatic averages Australia. Australian Government Publishing Service, Canberra.
- Coronel, R.E. (1983). Rambutan *in*: Promising fruits of the Philippines. University of Philippines, Los Banos.
- Tindall, H.D. (1994). Rambutan Cultivation. F.A.O. Plant Production and Protection Paper 121, Rome, Italy.
- van Welzen, P.C. and Verheij, E.W.M. (1991). *Nephelium lappaceum* L. in: Plant Resources of South-East Asia. No. 2, Edible fruits and nuts (Ed) E.W.M. Verheij and R.E. Coronel. Pudoc, Wageningen.

3.0 Environment and phenology monitoring of rambutan in the Top-End of the Northern Territory.

Y. Diczbalis, G. McMahon and C. Wicks

3.1 Introduction

The main phenological patterns of tropical tree crops include vegetative flushing, flowering, fruit development and harvest. Information on how the environment controls the rate and onset of these development patterns can be invaluable in the search for mechanisms which can be utilised to control major events such as flowering.

In many tropical tree crop species the environmental triggers which control flowering are not well understood (Chaikiattiyos, 1992). In some species a combination of triggers are required (temperature, drought, photoperiod and irradiance) where as in others a single environmental influence such as low temperature or soil moisture deficit is required.

In the rambutans native environment, peninsula Malaysia and Sarawak, flowering has been observed to occur at different times through out the year. In some areas two flowerings occur per year whereas in other regions only one distinct flowering and production period occurs (FAMA, 1988). Flowering is usually in response to a period of dry weather (Whitehead, 1959 as cited by Tindall, 1994; Valmayor et al. 1970; Tatt, 1976). Low night temperatures have also been implicated in the initiation of flowering in rambutan (Manakasem, 1995).

Rambutans were introduced into the wet/dry tropics (12-14°S) of the Northern Territory in the early 1980's (Lim and Diczbalis, 1995). Due to the distinct wet/dry conditions which occur in the Top-End, irrigation is an essential input if the crop is to be maintained through the eight months of the year where evaporation exceeds rainfall. Observations of commercial orchards suggested that growers were maintaining soil moisture at high levels through out the year, yet the flowering and fruit set was distinctly seasonal (June-September). A formal phenology and environmental monitoring program was initiated at the start of this project to improve our understanding of how the crop grows and develops in the harsh environment of northern Australia.

3.2 Materials and Methods

Three farms were selected and three trees per farm were monitored weekly for three years for soil moisture status (volumetric moisture measured with a Neutron Moisture Probe and soil tension as measured with tensiometers) and tree phenology (flushing, flowering, fruit set and harvest date). Other recordings included, weekly rainfall, irrigation and maximum and minimum temperatures.

The three rambutan orchards selected for monitoring are all 20 km or more apart. They consisted of two commercial sites (Karlsson (K) and Delis (D)) and one variety trial site at the DPIF Coastal Plains Research Station (CPRS). Orchard managers were not requested to undertake any particular irrigation or fertiliser management regime. Tree age varied from six to ten years at the start of the monitoring period.

The trees selected were not of the same cultivar, as the original commercial and CPRS planting were multi-varietal containing up to 16 different cultivars or accessions. The varieties monitored included R134, R160, R167, Chompoo, Jitlee and Rongrein.

3.2.1 Soil moisture monitoring

Soil moisture monitoring occurred on three sample trees within an irrigation block on each orchard. Soil volumetric moisture monitoring was undertaken with a Cambell 503DR Neutron Moisture Probe (NMP). Access tubes (aluminium) 1.5 m in length were installed to a depth of 1.4 m at a site which was 1.0 m from the sprinkler and 1.5 m from the tree trunk. Nine depths (10, 20, 30, 40, 50, 60, 80, 100 and 120 cm) were monitored at each tube. Data was down loaded onto a spreadsheet and mean volumetric soil moisture was calculated using a calibration equation developed for each site. Tensiometer tubes (20, 40 and 80 cm) were installed opposite to the NMP access tube at each tree site. Tensions were read weekly using a Loktronic tensiometer meter (Lok, 1988) and the tubes were maintained. Data was collated and means calculated.

3.2.2 Irrigation inputs and rainfall

Irrigation inputs were measured using a Amiad multi-jet water metre installed on a lateral line approximately 10 trees up from the end of the line. The position of the meter was determined by the total flow rate required to meet the minimum flow rate specifications of the meter. Accumulated flow readings (m^3) were made weekly and the inputs (L/tree) for the week calculated. Irrigation inputs were also expressed as mm per week by dividing the water inputs (L/tree) by the tree canopy area (m^2).

Rainfall inputs were measured and recorded weekly at each site using a Nylex rainfall gauge.

3.2.3 Weekly maximum and minimum temperatures

Temperature monitoring was undertaken using a Zeal, Max/min thermometer located within the canopy of one of the monitoring trees at each orchard. The thermometer was located in the lower branches so as to minimise the effect of sunflecks within the canopy. Data was collated and weekly maximum and minimum temperatures graphed.

3.2.4 Phenology recording

At each weekly visit trees were rated, on a whole tree basis, for their percentage flushing, flowering or fruiting activity (fruitset, colour changes and harvest). Data was recorded and means collated and six distinct phenological phases were identified (last major vegetative flush, early flowering, peak flowering, fruit set, fruit colour change and peak harvest).

3.3 Results

3.3.1 Volumetric soil moisture

Volumetric soil moisture (VSM) varied throughout the year and from year to year for the three orchards (Figures 1-9). Generally, VSM peaked during the wet season (when weekly

rainfall inputs ranged from 50 to 250 mm) and was at its lowest in the April to June period (generally pre-flowering) following the end of the wet season.

3.3.2 *Soil tension*

Soil tension was generally a mirror image of the VSM levels (Figures 1-9). In some cases the comparative movements between VSM and soil tension are quite clear. Soil tension appeared to be a more sensitive indicator of soil moisture status than VSM. Rapid changes in soil tension can take place at a particular depth (usually in the shallow or deeper soil horizons) with soil moisture remaining fairly stable in the remainder of the profile. At all three sites in all years, tension peaked during the pre-flowering period (April to June) following the end of the wet season. In all cases, tension at 20 and 40 cm depth exceeded 0.06 MPa some time during the monitoring period without any visual indications of plant stress.

3.3.3 *Irrigation and rainfall inputs*

Irrigation and rainfall records were not complete for the first half of 1992 for all sites and hence the values in Figures 1-9 should be interpreted with this in mind. The distribution between rainfall and irrigation inputs is distinctly seasonal as one would expect given the wet/dry tropical nature of the growing environment. Rainfall inputs were recorded from September through to May with peak falls occurring from December to the end of March. In most years at all sites weekly rainfall inputs exceed 250 mm at least once during the peak rainfall period. No rain was recorded from mid May until the end of August over the three year monitoring period.

Irrigation inputs occurred through out the year and were at their least during the peak of the wet season with inputs generally nil when rainfall exceeded 50 mm per week. During the dry season irrigation inputs were generally less than 50 mm per week prior to flowering and were at or exceeded 50 mm/wk from flowering through to harvest.

3.3.4 *Temperature*

The weekly maximum and minimum temperature data varies from year to year and site (Figures 1-9). However, the important consistency are the relatively stable weekly maximum temperatures throughout the year and the seasonal change in weekly minimum temperatures.

Weekly maximum temperatures in the orchards ranged between 32° and 38°C throughout the year with only odd differences due to local climatic or recording peculiarities. Weekly minimum temperatures changed during the year in four distinct phases. Phase one consists of the warmest nights which are experienced from mid September to mid April where the weekly minimums range between 20° and 25°C. Phase two is from mid April through to mid June during which there is a gradual, although not necessarily uniform, decline in weekly minimum temperatures. Phase three, from mid June to mid August is the coolest part of the year when weekly minimums can drop to 7°C, although the mean weekly minimum during this period is approximately 15°C. Phase four, from mid August to mid September is the period during which weekly minimums gradually return to their warmest.

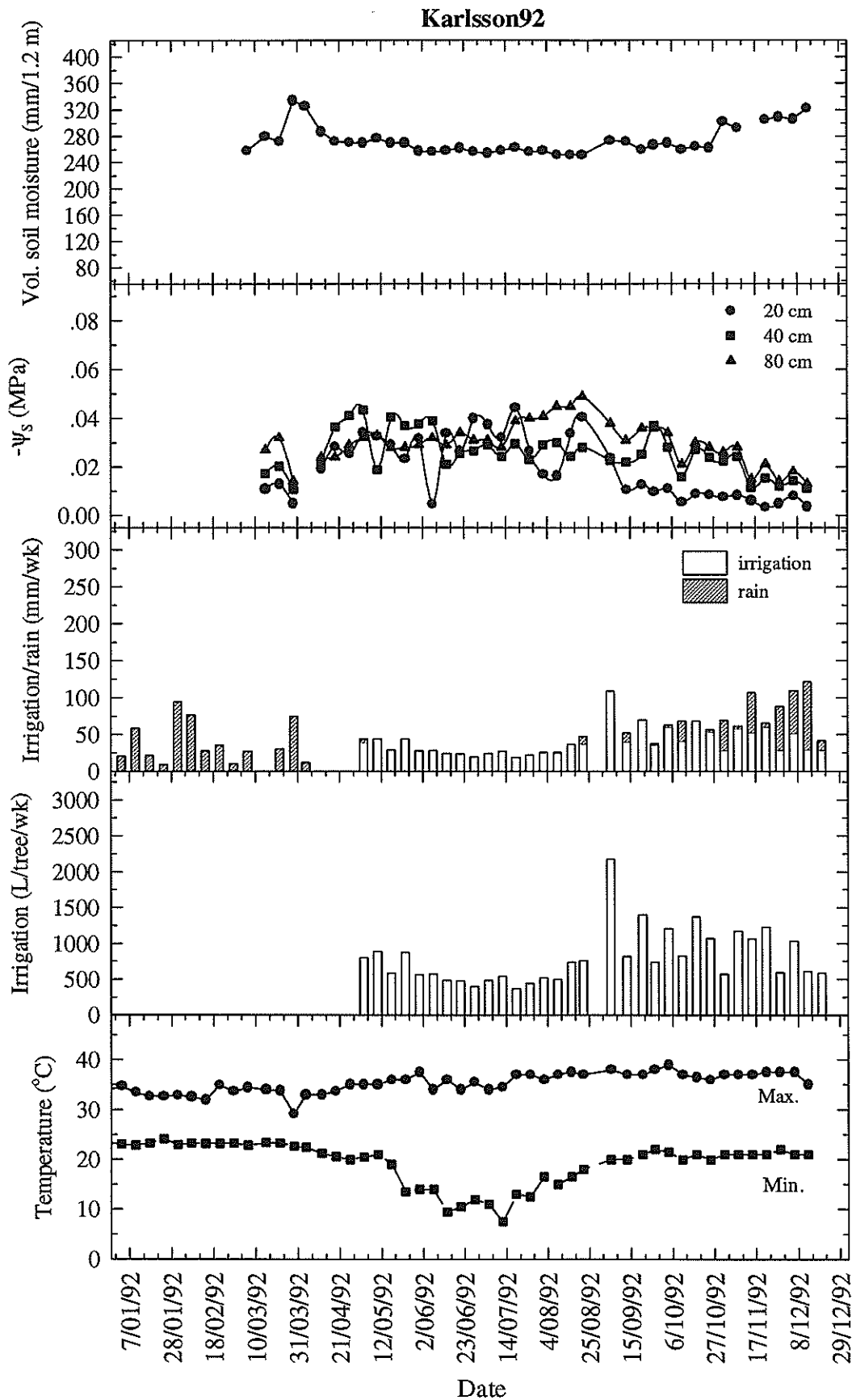


Figure 1. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for Karlsson orchard 1992.

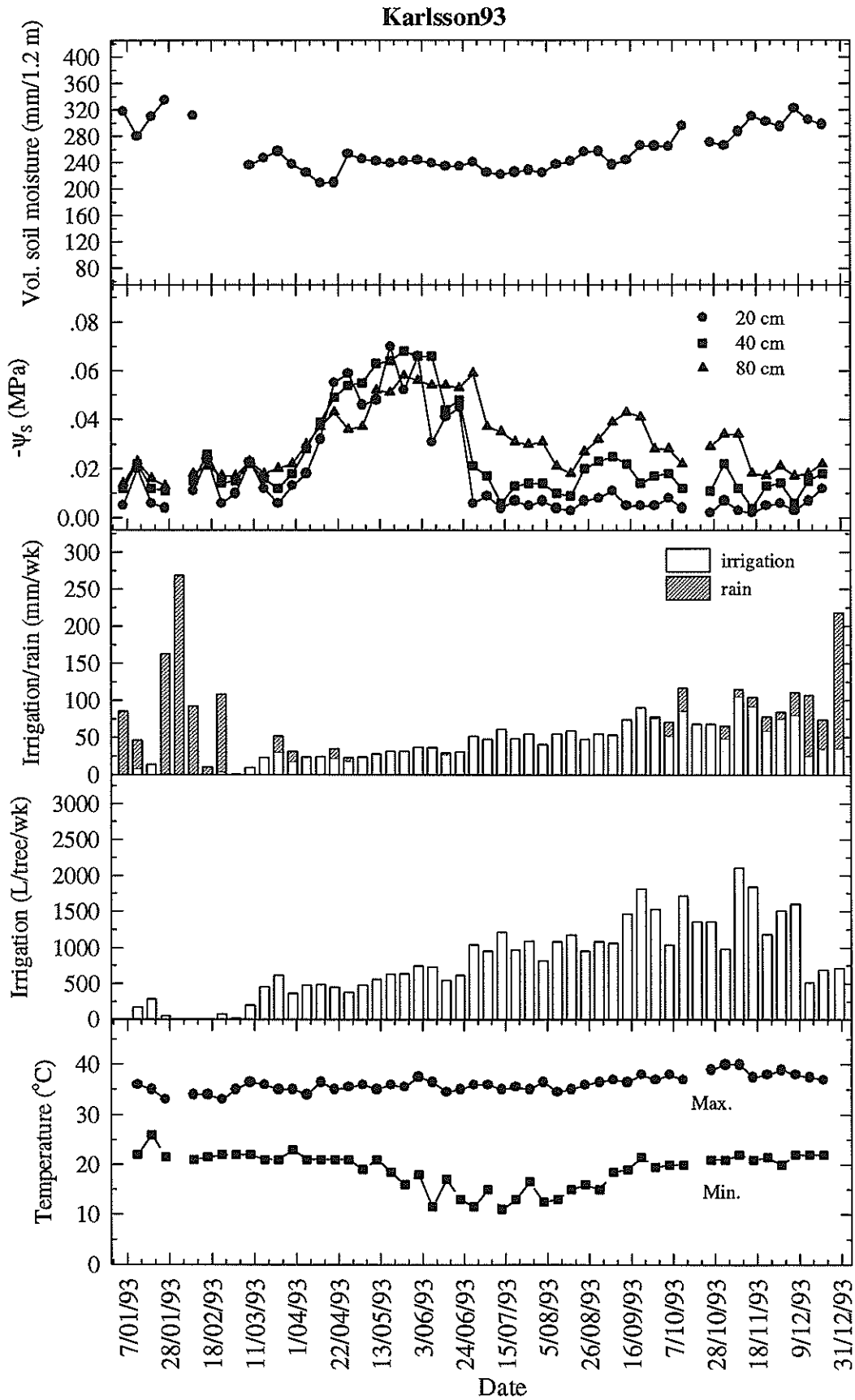


Figure 2. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for Karlsson orchard 1993.

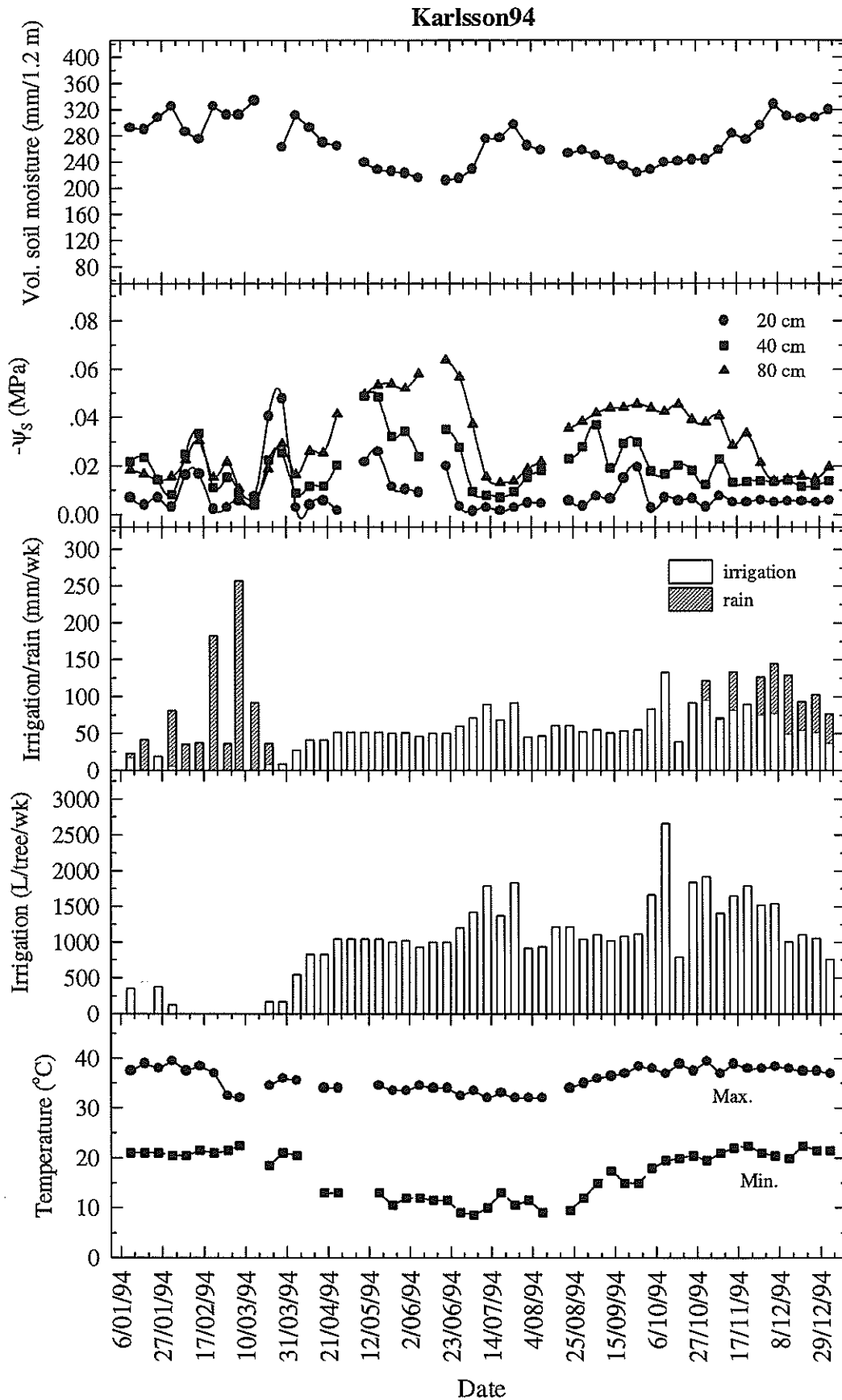


Figure 3. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for Karlsson orchard 1994.

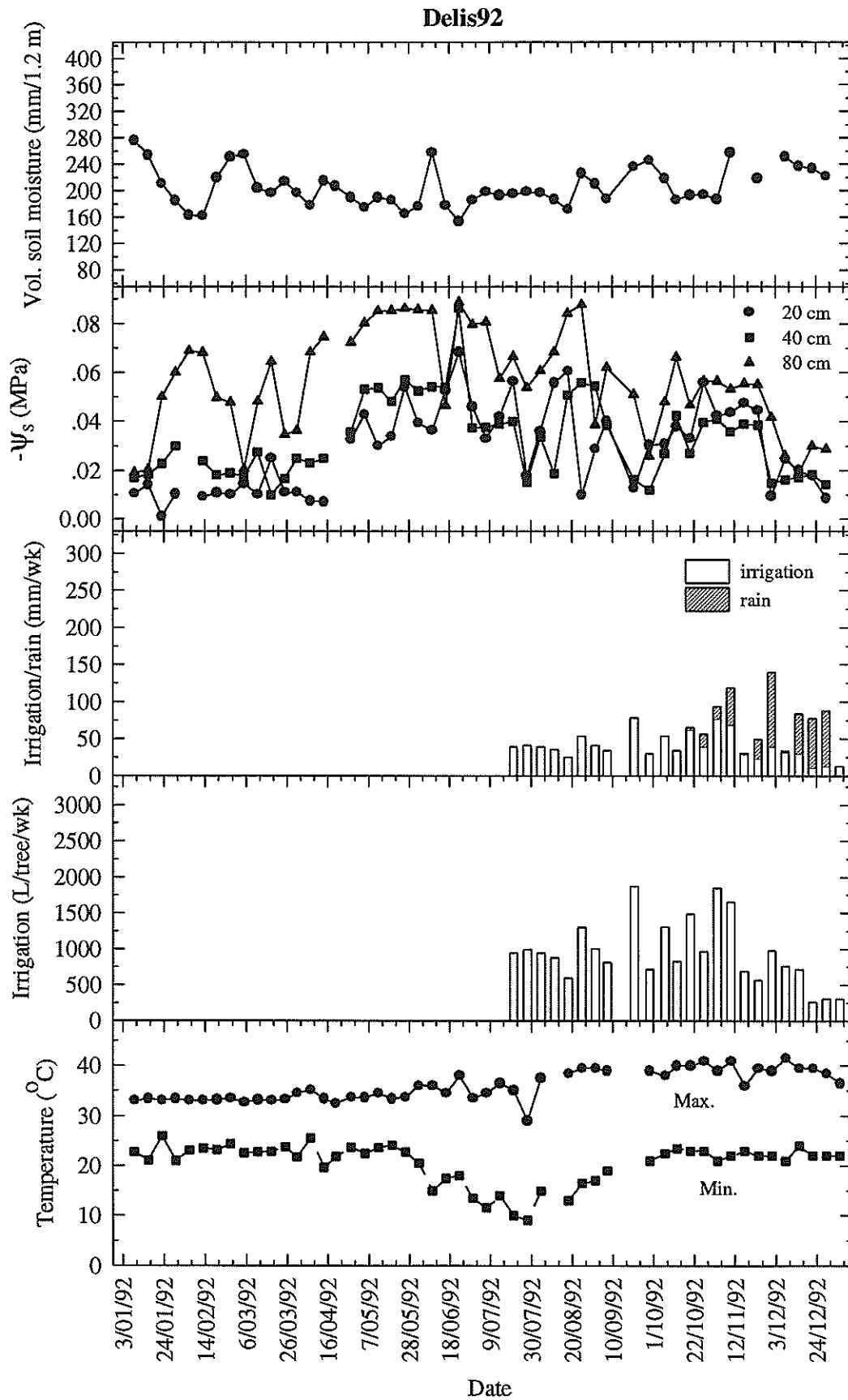


Figure 4. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for Delis orchard 1992.

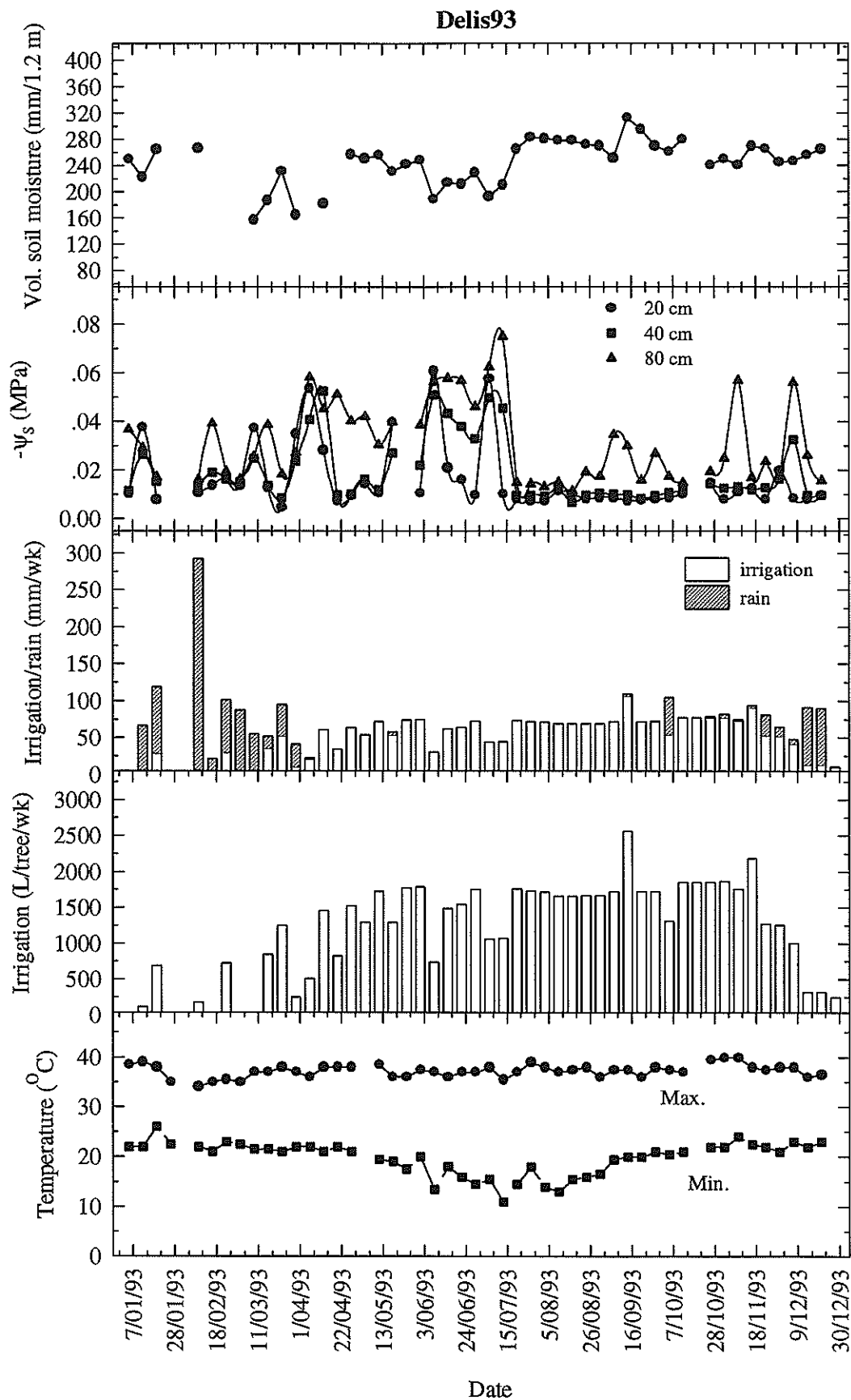


Figure 5. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (L/tree/wk) and weekly maximum and minimum temperatures for Delis orchard 1993.

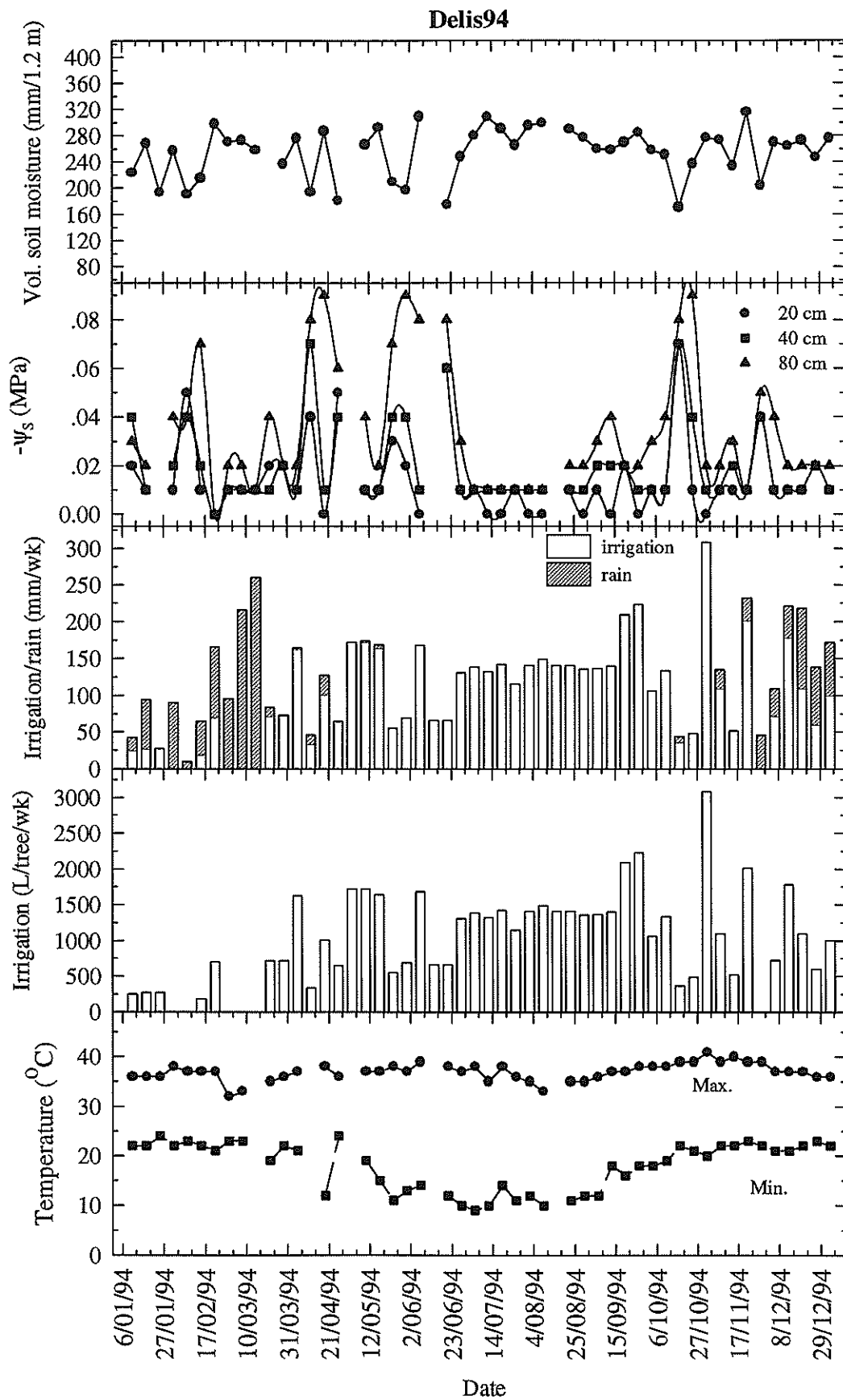


Figure 6. Total soil moisture, soil tension, ($-\Psi_s$, MPa) irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for Delis orchard 1994.

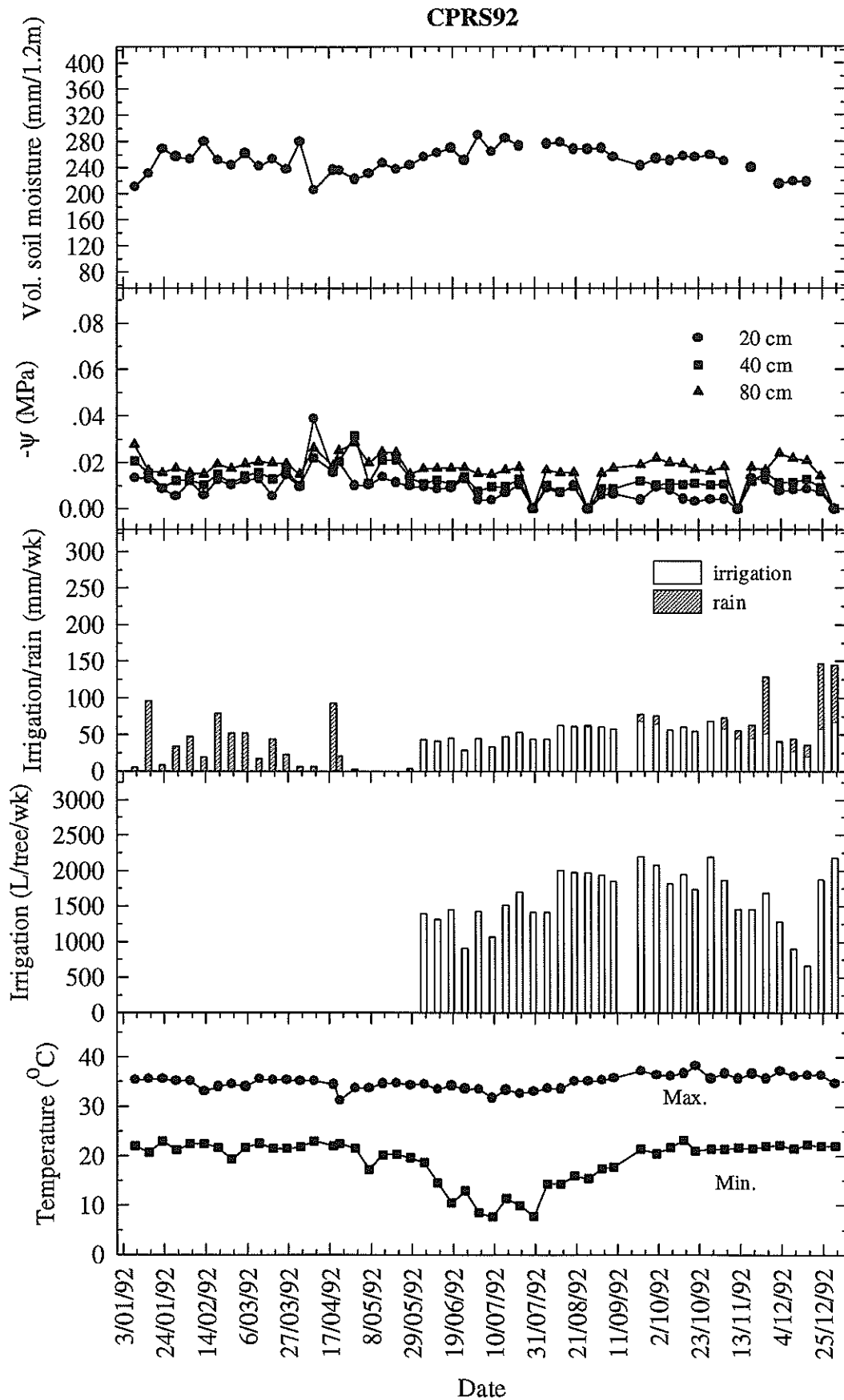


Figure 7. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for CPRS orchard 1992.

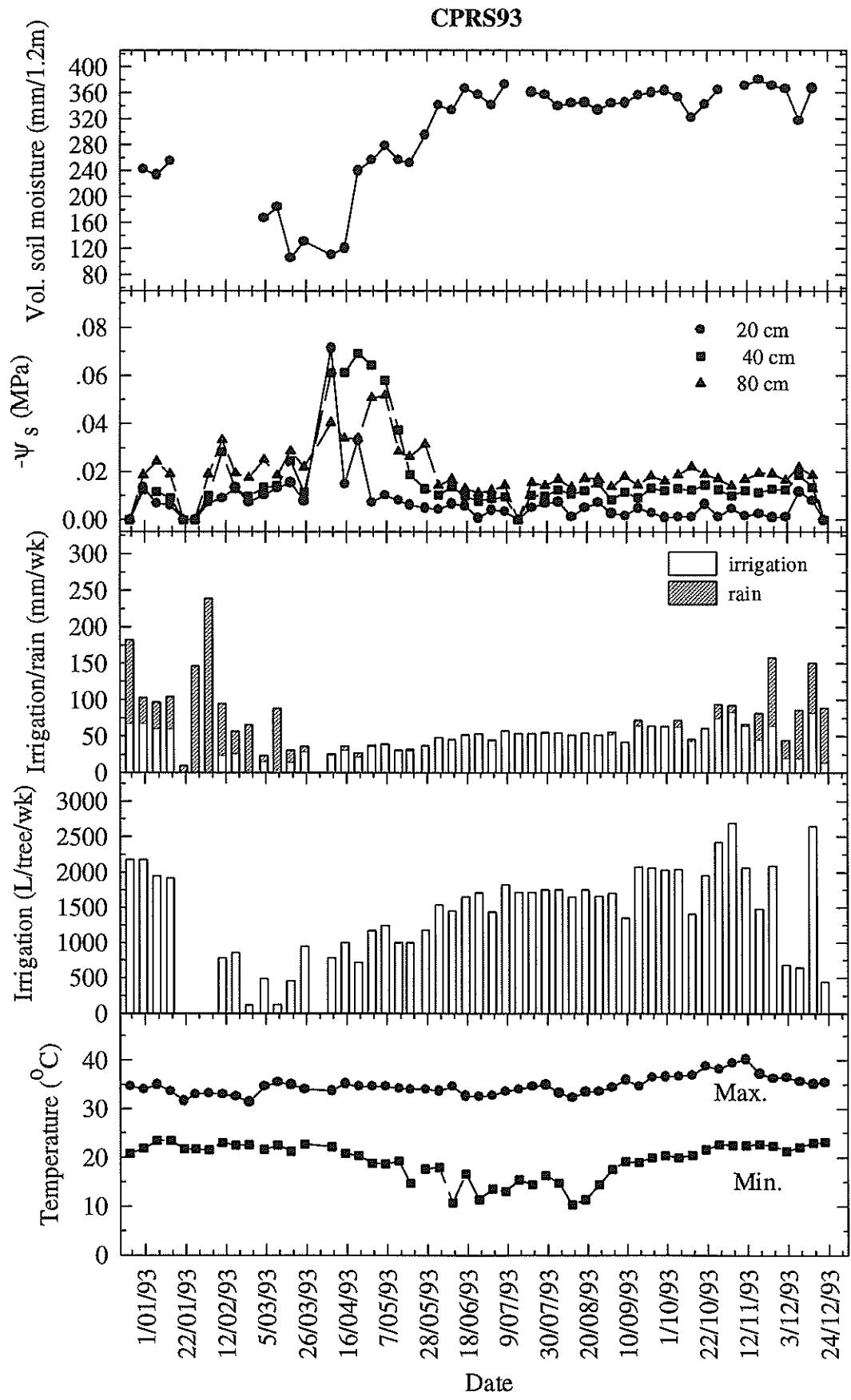


Figure 8. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for CPRS orchard 1993.

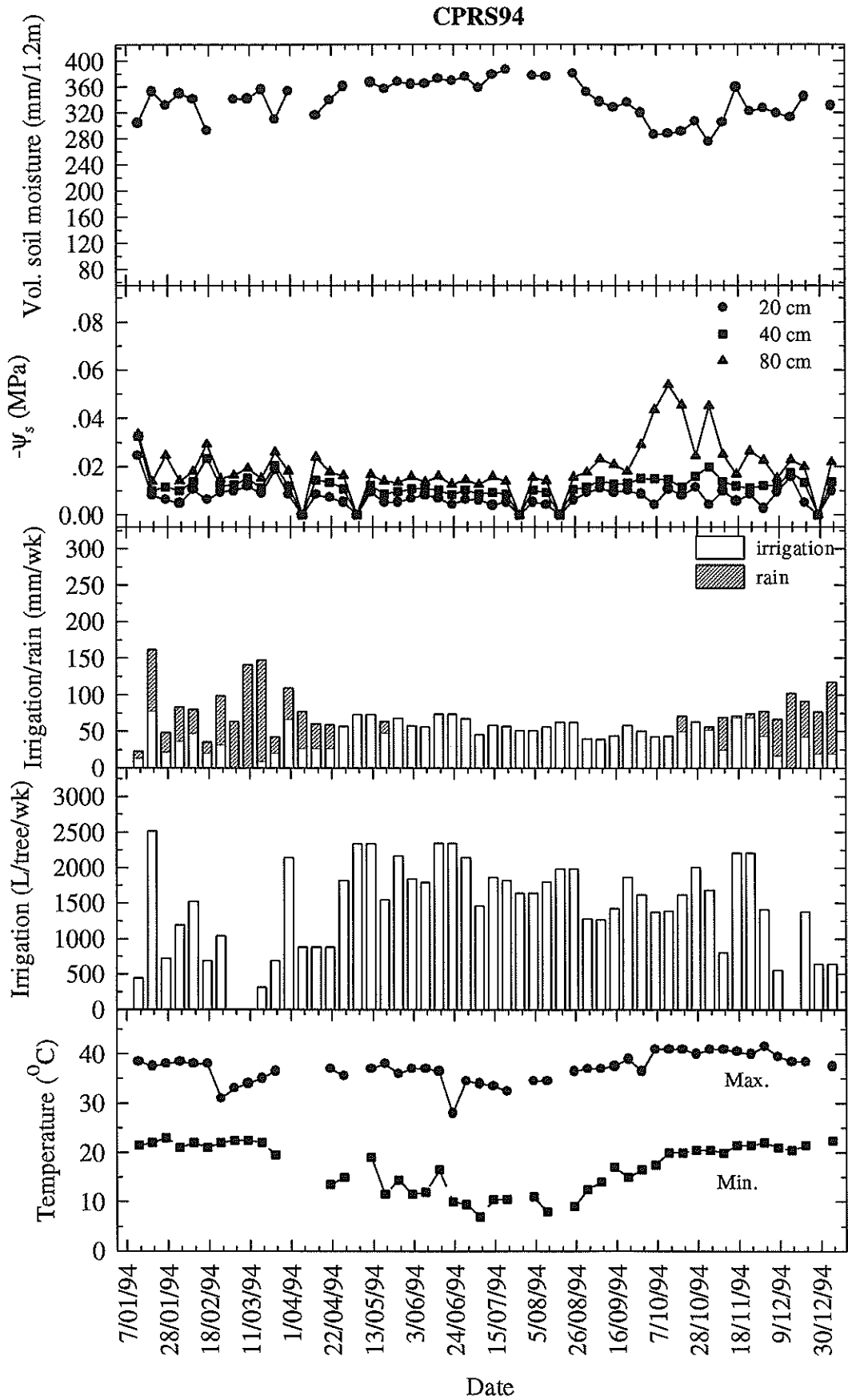


Figure 9. Total soil moisture, soil tension ($-\Psi_s$, MPa), irrigation and rainfall inputs (mm/wk), irrigation inputs (l/tree/wk) and weekly maximum and minimum temperatures for CPRS orchard 1994.

3.3.5 Phenological events

Table 7 summarises the major phenological events for the three orchards over the three seasons. There is a large variation in timing of the major phases between orchards and from year to year. The event with the greatest range in timing is last major flush where the difference between the earliest and last recorded event was 107 days (4 March-19 June). The range in timing for phases 2 to 5 was approximately 50 days and the event with the least variability is peak harvest which had a range in timing of 27 days (26 November-23 December).

The mean dates for the major events give some indication of what may be expected in an average season. Figure 10 gives an indication of the mean pattern of phenological activity throughout the year. On average there are approximately four vegetative flushing spurts from January through to the end of May. The last vegetative flush will generally occur in mid May, shortly after the decline in minimum weekly temperatures. The first signs of flowering are expected by late June following the onset of cool nights and a relatively dormant period of vegetative growth. Peak flowering does not occur until mid August which is generally the coolest part of the season. Peak fruit set occurs in early September as the night temperatures are warming up. Early colour change occurs in early November with peak harvest occurring in mid December some 104 days after peak fruit set.

Table 7. Summary of major phenological events for rambutans grown at three orchards over three seasons (1992-1994) in the Top-End of the Northern Territory.

Grower/ Year	Phenological stage #					
	1	2	3	4	5	6
K92	19-Jun	16-Jul	20-Aug	6-Sep	23-Nov	21-Dec
K93	13-Jun	1-Jul	29-Jul	19-Aug	4-Nov	23-Dec
K94	12-May	12-Jun	18-Aug	2-Sep	24-Oct	15-Dec
D92	2-May	2-Jul	16-Jul	20-Aug	7-Nov	17-Dec
D93	11-May	24-Jun	19-Aug	2-Sep	4-Nov	16-Dec
D94	9-Jun	26-Jun	21-Jul	4-Aug	9-Oct	8-Dec
CPRS92	7-May	19-Jun	3-Sep	24-Sep	21-Nov	11-Dec
CPRS93	4-Mar	28-Jul	27-Aug	13-Sep	2-Nov	26-Nov
CPRS94	22-Apr	3-Jun	5-Sep	16-Sep	11-Nov	23-Dec
Mean	11 May	27 Jun	14 Aug	1 Sep	4 Nov	14 Dec
Range	4 Mar - 19 Jun	3 Jun - 28 Jul	16 Jul - 5 Sep	4 Aug - 24 Sep	9 Oct - 23 Nov	26 Nov - 23 Dec

#Phenological stage

1 - last major vegetative flush; 2 - early flowering; 3 - peak flowering; 4 - peak fruit set; 5 - early fruit colour change; 6 - peak harvest

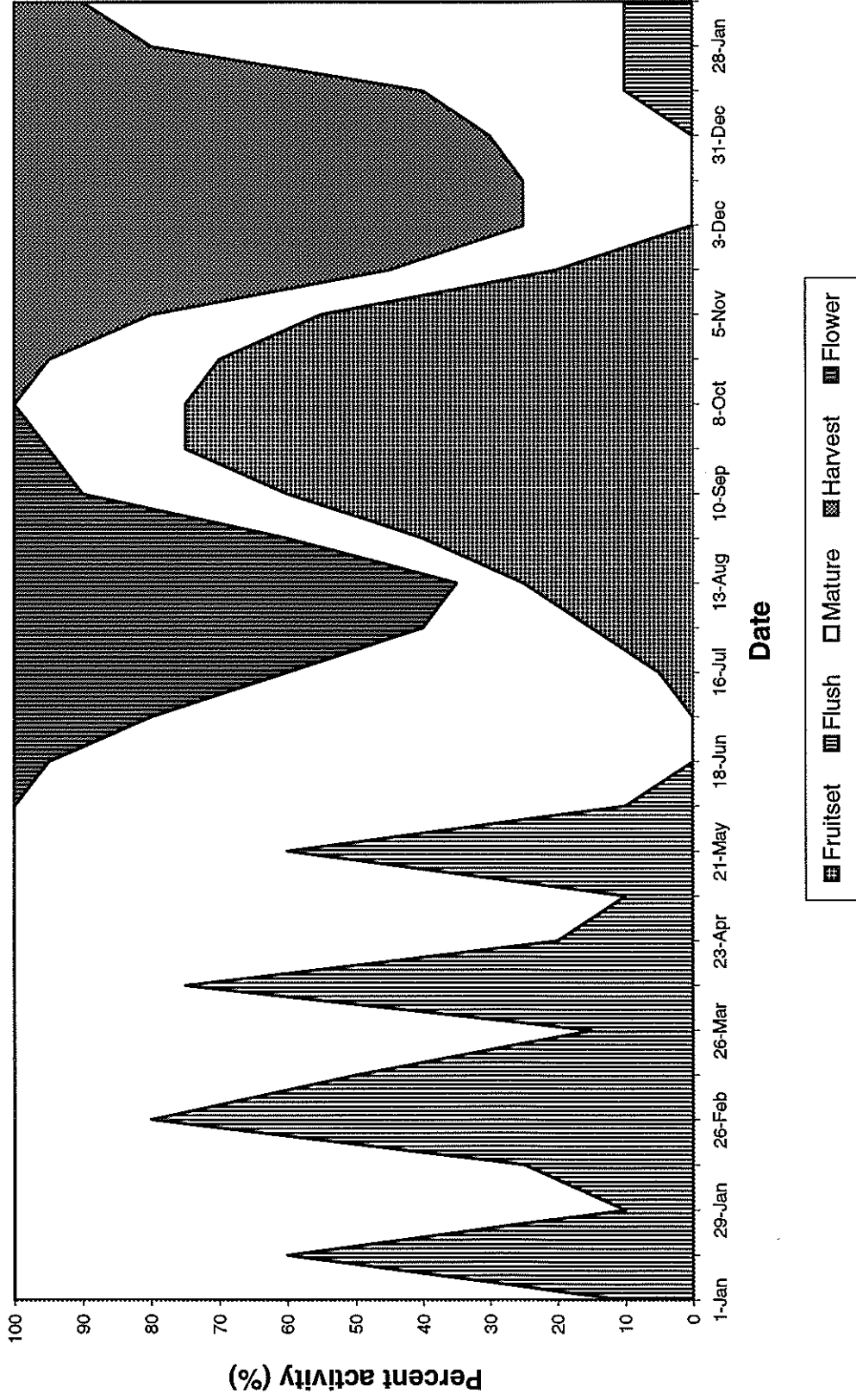


Figure 10. Average phenological activity for rambutans in the Top-End of northern Australia.

3.4 Discussion

The phenology of rambutan grown in the Top-End of the Northern Territory is closely related to the environmental changes which occur through out the year.

Vegetative flushing mainly occurs following the cessation of harvest, although minor flushing can occur on terminals which have not flowered during the later stages of fruit fill and while fruiting terminals are being harvested. Four major vegetative flushing peaks occur from January through to late May. This flushing activity occurs during a time of high mean temperatures and high rainfall inputs, although the two later flushing periods (April and May) occur during the onset of the dry season when soil moisture levels are maintained through irrigation inputs.

The onset of relatively low minimum temperatures appears to cause a cessation in vegetative growth and an increase in reproductive activity. This is in contrast to data from Malaysia which suggests that the seasonality in flowering occurs in response to short periods of dry conditions. In Malaysia, rambutans grown in areas where there are two dry periods per year often flower twice although one flowering is usually more dominant than the other (Whitehead, 1959 as cited by Tindall, 1994; Tatt, 1976). In the Philippines, Valmayor *et al.* (1970) also suggest that flowering occurs in response to the cessation of the rainy season. In Thailand, Wanichkul *et al.* (1990) showed that non-structural carbohydrate content of leaves increased during a period of water stress and preceded flower bud initiation. The accumulation of carbohydrate was thought to be due to reduced root growth during the dry period. Climatic data during their experiment indicated that the mean temperature dropped 3°C on the cessation of the rainy season and hence could have also influenced floral initiation. Manakasem (1995) showed that in rambutans grown in Chantaburi, Thailand, at latitudes similar to those in this study, minimum temperature and rainfall amount were negatively correlated with percentage flowering and that maximum floral initiation occurred as minimum temperatures dropped below 23°C. The environmental trigger's controlling flowering of rambutan in north Queensland are not clear. Watson (1988) states that flowering in the Cairns area (16°S) commences in July/August and may continue on different trees or parts of the same tree until April. He states that flowering occurs in cold, dry, wet and hot periods and is not affected by cool weather or climate changes from wet to dry.

In this study, phenological data collected suggests that soil moisture status prior to flowering did not influence the onset of flowering or peak flowering, as first flowering always occurred following the onset of cool nights. The duration between the onset of cooler nights and first flowering is also variable. The weekly minimums recorded in this study are well below those recorded in Asian growing areas and hence although they may assist in the floral initiation process they may also slow down the rate of floral development and its expression as a flowering panicle. Rambutans have been reported to be susceptible to low temperatures, although Watson (1988) stated that plants may tolerate brief periods of temperature as low as 5-6°C. The temperature minimums experienced during this study ranged from 7-10°C for a number of weeks, during the dry season, without any adverse effect on tree health besides reduced vegetative vigour.

Despite the rambutans tolerance to short periods of low temperatures, Watson (1988) suggested that rambutan cultivation in north Queensland should be avoided in areas where the mean minimum July temperature is less than 15°C. Hobman (1984) reported that the clones

differed in their tolerance to cold and R6, R7 and R156 were susceptible to short term exposure to temperatures below 10°C. Controlled environment work reported in this study (Diczbalis and Menzel, Chapter 7) suggests that extended periods at 18°C are more restrictive to growth than the short periods of low temperature (< 10°C) experienced by plants grown in the field. Further analysis of the relationship between floral initiation and temperature using daily temperature data would enhance our understanding of the initiation and floral development process.

Fruit set and development are phases which are known to be temperature dependent. In this study, peak flowering of rambutan occurs in mid August when the minimum temperatures are usually at their lowest. Peak fruit set occurs in early September when night temperatures are on the increase. Although the period between flowering and fruit set may be temperature dependent the delay reported between fruitset and flowering is not unusual. Tindall (1994) reports that the period between peak flowering and fruitset in Malaysia ranges from three to four weeks. Low temperatures can interfere with the fruit setting process. During the course of the phenology monitoring flowers have been observed to die and new flowers to develop on an extended raceme until night temperatures were warm enough for fruit set to occur.

The period from fruit set to harvest is reported to be in the range of 13 to 16 weeks (Salma, 1983; Wanichkul and Kosiyachinda, 1982 as cited by Tindall 1994). In the Northern Territory this period is on average 14.8 weeks. The heat units required to complete fruit development have not been calculated, however, there is no doubt that the duration of this period is temperature dependent and in seasons where cool nights extend into September fruit maturity will be delayed. Watson (1988) indicates that the fruit development period in north Queensland can vary from three to five months depending on time of flowering.

The trigger for flowering in rambutan appears to follow the cessation of vegetative growth, whether caused by drought or low temperatures. A number of authors have suggested that a lack of vegetative growth allows a build up of carbohydrates which then triggers flowering (Scholefield *et al.* 1985, Menzel *et al.* 1989). Hence in Malaysia where the temperature range in Rambutan growing areas is in the range 21°-28 °C, soil moisture deficits as a result of low rainfall inputs is the important flowering trigger. Changes in solar radiation inputs and humidity may also be implicated but there is currently no evidence to suggest this. In the higher latitude growing areas of Thailand both drought and falls in temperature have been shown to trigger flowering. In most growing regions it appears that the cession of vegetative growth is a precursor to flowering.

In the Northern Territory, our long dry season, often commencing prior to the onset of cooler nights, may provide an ideal environment to test the hypothesis that cessation of vegetative growth is the only important percussor to flowering. However, it is unlikely that only one environmental variable is responsible for flowering in rambutan as the onset of the dry season in tropical environments is often accompanied by other changes in the climatic conditions, such as lower humidity, higher radiation and a drop in night temperatures. The effect of soil moisture deficit on flowering is reported in Chapter 9.

3.5 References

- Chaikiattiyos S. (1992). Floral induction in tropical trees. PhD Thesis, Department of Botany, University of Queensland, Australia.
- FAMA (1988). Exotic fruits of Malaysia. Federal Agricultural Marketing Authority, Kuala Lumpur, Malaysia.
- Hobman, F.R. (1984). Preliminary assessment of rambutan clones in Australia. *Queensland Journal of Agricultural and Animal Sciences*. 41:115-119.
- Lim, T.K. and Diczbalis, Y. (1995). Rambutan. in *Horticulture Australia*, (ed) B. Coombs, Morescope Publishing Pty, Ltd, Melbourne.
- Lok, J.W.D. (1988). The use of tensiometry in irrigation scheduling. *in Proceedings of the Fourth International Micro-irrigation Congress, Volume Two, Albury-Wodonga, Australia*.
- Manakasem, Y. (1995). Changes in apices and effect of microclimate on floral initiation of rambutan (*Nephelium lappaceum* L.). (In Thai) *Suranaree Journal of Science and Technology* 2:81-87.
- Menzel, C.M., Rasmussen, T.S. and Simpson, D.R. (1989). Effects of temperature and leaf water stress on growth and flowering of litchi (*Litchi chinensis* Sonn.). *The Journal of Horticultural Science*. 64:739-752.
- Scholefield, P.B., Sedgley, M., and Alexander, D.M. (1985). Carbohydrate cycling in relation to shoot growth, floral initiation and development and yield in avocado. *Scientia Horticulturae*. 25:99-110.
- Tatt, O.H. (1976). Climatic changes in water balance and their effects on tropical flowering. *Planter, Kuala Lumpur* 52:174-179.
- Tindall, H.D. (1994). Rambutan cultivation. *FAO Plant Production and Protection Paper* 121. Food and Agriculture Organization of the United Nation.
- Valmayor, R.V., Mendoza, D.B., Aycardo, H.B. and Palencia, C.O. (1970). Growth and flowering habits, floral biology and yield of rambutan (*Nephelium lappaceum* Linn.). *Philippine Agriculturist* 52:359-374.
- Wanichkul, K., Osotsapa, Y., Subhadrabandha, s., Masuthon, S., Kaewprasit C and Nakorn M. (1990). Effects of climatic factors on total non-structural carbohydrates, total nitrogen in leaves and flower bud initiation of rambutan (*Nephelium lappaceum* L. cv Rong Rian). (In Thai) *Kasetsart Journal Natural Sciences* 24:8-15.
- Watson, B.J. (1988). Rambutan cultivars in north Queensland. *Queensland Agricultural Journal*, Jan-Feb. 37-41.

4.0 Effect of various irrigation schedules on plant and soil water status and physiology of container grown rambutans.

Y. Diczbalis and D. Eamus

4.1 Introduction

The rambutan (*Nephelium lappaceum*) is native to West Malaysia and the island of Sumatra in Indonesia (Watson, 1984). The crop is grown in a number of locations outside its natural distribution, including the greater part of SE Asia, Central America, Africa and northern Australia. In north eastern Australia, plantings are restricted to the north of 14°S. Areas further south than those described are not suitable due to the likelihood of experiencing extended periods of mean minimum temperatures below 15°C.

The native environment of the rambutan is characterised by high rainfall (evenly distributed), high humidity, low evaporation rates and average minimum temperatures above 20°C. The water requirements of the trees is supplied by rainfall and periods where evaporation exceeds rainfall are rare. In northern Australia and in particular the top end of the Northern Territory (latitude 10-12°S) rainfall is relatively high (1665 mm/year), but poorly distributed. During eight months of the year evaporation (2685 mm/year) exceeds rainfall inputs with little or no rainfall occurring for four to six months of the year (May - October).

Supplementary irrigation is a necessary part of production in this environment. Current irrigation management in commercial orchards is *ad-hoc* and based on a few years of experience. Overall, there is a poor understanding of rambutan water requirements and irrigation management.

An experiment was designed to test the trees physiological response to varying irrigation schedules. The aim of the work is to improve irrigation scheduling recommendations for commercial orchards.

4.2 Materials and Methods

Twenty four, eighteen-month old bud grafted rambutan trees (cv. Jitlee and R134) were planted (April 1991) into 200 L containers, filled with a red sandy clay loam. The containers were placed outdoors in three blocks of eight trees (Plate 1). The plants were irrigated daily, with the aid of an automatic controller and drip irrigation system which ensured that the entire soil surface was wetted up at each irrigation. Basal fertiliser (80 g/pot of NPK 10:12:11 + micronutrients) was applied monthly. Foliar applications consisting of (ZnSO₄ 1.0g/l, MgSO₄ 1.0g/l, FeSO₄ 1.0g/l) were applied fortnightly. The plants were allowed to establish in the pots over a sixteen month period prior to initiation of treatments.

Control of insect pests, chiefly *Myoseerus* sp. was carried out on an as-needed basis using carbaryl (3.0 gm/litre).

The trial was initiated on 18 August 1992, consisted of four irrigation treatments; daily irrigation, 2nd daily irrigation, 3rd daily irrigation and irrigation following severe plant wilt (six days). The irrigation treatments were imposed on two cultivars Jitlee and R134. Each treatment was replicated three times. The majority of plants had some early flowering shoots.

Irrigations, when scheduled, occurred from 1630 hours. Sufficient water was applied to saturate the soil so that free drainage occurred. On the afternoon of day six when all plants of both cultivars, in the non-watered treatment were showing symptoms of severe water stress (leaf curling, discolouration and leaf drop) all plants regardless of treatment were irrigated to saturation. Recovery measurements were carried out on the following day.

Plant and soil moisture status measurements and plant physiological measurements were carried out daily over a seven day period and consisted of the following. Data are presented as means and associated standard errors (SE).

4.2.1 Leaf water potential (Ψ_L)

Leaf water potential measurements occurred at 0615-0645 h, 11.30-12.00 h and 1500-1530 h using a Soil Moisture Corporation (USA) pressure bomb. The youngest fully expanded leaf on the sunlit side of each plant (except for pre-dawn sample) was sampled, enclosed in a plastic bag and transferred to the pressure bomb within 60 seconds and the cut end of the petiole was observed with a magnifying glass for the 'end' point (Scholander *et al.*, 1965).

4.2.2 Relative water content (RWC)

Leaves were sampled for relative water content measurements at 0645 h, following leaf water potential measurements. The youngest fully expanded leaf on a shoot in the upper third of the canopy was cut and placed in a plastic bag. As leaves were sampled, they were placed in an insulated container. Following sampling of all treatments, the leaves were taken to the laboratory where five leaf disks were cut from each sample using a 19 mm diameter punch. Any surface moisture, due to dew, was removed using tissue paper and the fresh weight of the five disks was obtained using a Mettler ® H6, 4 decimal place balance. The leaf disks were then floated on distilled water under a double tubed fluorescent light (30 cm from the leaf surface) for four hours. Turgid weights for the leaf disks, following the removal of surface moisture, were then obtained. The disks were then dried at 65 °C for a minimum of 48 hours and the dry weight established. The RWC was calculated using the formula:

$$\text{RWC(\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

4.2.3 Leaf photosynthesis

Net CO₂ assimilation (A) and ancillary data such as conductance (g_s) transpiration (E), and internal CO₂ (C_i) along with environmental variables such as air temperature, photon flux density (Q) vapour pressure deficit (VPD) and ambient carbon dioxide levels (C_a) were measured from 0900-1030 hours and 1330-1500 hours using a LICOR 6200 (Licor ®, Nebraska, USA) portable photosynthesis system.

4.2.4 Soil moisture tension

Soil moisture tension was monitored in each container at 15 and 40 cm depths at 0800 h and 1600 h using tensiometers. The tensiometers were read using a Loktronic® meter with a digital readout in millibars (J. Lok, 1988).

4.3 Results

4.3.1 Soil moisture tension

Monitoring of soil moisture tension indicated that the imposed irrigation treatments resulted in distinctly different soil moisture tension regimes over the period of the experiment. Morning soil moisture tensions (Figure 11) under daily irrigations did not fall below -0.01 MPa at both 15 and 40 cm depth. The afternoon readings, not shown, at 15 cm depth were in the range of 0.01 to 0.015 MPa higher whereas at 40 cm there was virtually no change in soil tension. For the 2nd and 3rd daily irrigation treatments, there was a cyclical pattern with tensions increasing rapidly up to re-watering and then falling sharply on re-watering. For the non-watered treatment, tensions at 15 cm depth reached a peak on the morning of day three and on the morning of day four at 40 cm depth for the cv. R134. For the cv. Jitlee, peak tensions at both depths were reached on day five. Afternoon readings (not shown) were generally lower than morning readings which was the reverse to what occurred in the other watering treatments. The patterns of soil moisture tensions were not greatly different between varieties.

4.3.2 Leaf water potential

Dawn, noon and afternoon Ψ_L for both varieties are shown in Figure 12. Dawn Ψ_L for both cultivars remained between 0 and -0.6 MPa for the daily, 2nd daily and 3rd daily irrigation treatments throughout the duration of the trial. The Ψ_L for the non-watered treatments decreased from day two to a peak at day five. For both varieties, Ψ_L increased on day six. On day seven, following re-watering, dawn Ψ_L for all treatments were similar -0.3 to -0.4 MPa.

Noon Ψ_L trends over time were dissimilar for the two cultivars. For R134, Ψ_L in the daily and 2nd daily irrigation treatment were similar and ranged between -0.55 MPa and -1.20 MPa. The Ψ_L for the non-irrigated treatment fell steadily to a low of -2.20 MPa at day six. For the 3rd daily irrigation treatment Ψ_L fell to -0.2 MPa on day three and decreased to -0.6 MPa on day four and remained at that for the remaining four days. Leaf water potential for the variety Jitlee were erratic, particularly for the non-watered treatment. For the daily, 2nd daily and 3rd daily irrigation treatment Ψ_L ranged between -0.6 and -1.50 MPa, with the lowest potentials being measured in the 3rd daily irrigation treatments the day prior to re-watering.

Afternoon Ψ_L followed a similar trend to the noon readings, particularly for cultivar R134. For Jitlee, the peaks and lows were opposite those recorded at noon. Readings are not available for day six.

4.3.3 Relative Water Content (RWC)

Relative water content data, shown in Figure 13, were similar for the daily, 2nd daily and 3rd daily irrigation treatments over time. Means of these treatments were not significantly different. Relative water content dropped to 77.1% on day six, in both varieties. There appears to be no differences between varieties.

4.3.4 LICOR Measurements (0900 - 1030 h)

a. Net CO₂ assimilation (A)

Net CO₂ assimilation in plants watered daily varied over the seven days from a low of 5.6 to a high of 10.6 $\mu\text{mol m}^{-2}\text{s}^{-1}$ (Figure 14). The average rate of photosynthesis over the seven day period for daily watered trees was higher for the cultivar Jitlee. In the 2nd daily irrigation treatment for the cultivars R134 & Jitlee, photosynthesis was similar to that which occurred in the daily irrigation treatment. In the 3rd daily irrigation treatment, photosynthesis fell until re-watering for R134, but not for Jitlee. Following watering, photosynthesis increased but fell away by the third day of the second cycle. For the cultivar Jitlee, photosynthesis fell to near zero at the end of the second dry period.

In the non-watered treatment, photosynthesis fell rapidly and was at 1.0 $\mu\text{mol m}^{-2}\text{s}^{-1}$ or less by the fourth day for both cultivars. There was some sign of recovery for the cultivar R134 following re-watering on the evening of day six.

b. Stomatal Conductance (g_s)

Stomatal conductance results (Figure 15) generally mirrored the A data. Conductance values for plants watered daily varied from a low of 90 to a high of 250 $\text{mmol m}^{-2}\text{s}^{-1}$ for both varieties. Data varied with time, and between irrigation treatments. There was no difference between varieties.

There was no significant difference in g_s between irrigation treatments on day two of the trial. Thereafter, g_s tended to separate with time. Thus, for Jitlee, g_s was constantly higher for the daily irrigated trees compared to the other irrigation treatments (Figure 15), whilst the non-irrigated trees exhibited the lowest g_s values on days 4 -7 of the trial. On average the g_s of the 3rd daily irrigated treatment was lower than the 2nd daily irrigated trees. For R134 the highest average g_s was exhibited for the daily and 2nd daily irrigated trees, whilst the lowest g_s was observed for the non-irrigated trees. The 3rd daily irrigated trees maintained a g_s value intermediate between the two extremes.

c. Transpiration (E)

Transpiration data (Figure 16) were similar to g_s data. E rates for plants watered daily varied from a low of 3.1 to a high of 5.0 $\text{mmol m}^{-2}\text{s}^{-1}$ over both varieties. Data varied with time and between irrigation and variety treatments and for irrigation by variety interactions.

Transpiration remained high for both cultivars when irrigated daily. E was markedly lower for the 2nd daily watered trees of Cultivar Jitlee, but there was no difference between daily and 2nd daily irrigated treatments for R134. In both cultivars, E was the lowest for the non irrigated plants, whilst the 3rd daily trees were intermediate between these and the 2nd daily irrigated treatment.

d. C_i/C_a

The ratio of internal to external CO_2 concentrations expressed as C_i/C_a shows that for daily and 2nd daily irrigation treatments, there was no variation over time (Figure 17) for either cultivar. In the 3rd daily irrigation treatments, no change occurred in C_i/C_a for the variety R134. However, in Jitlee the C_i/C_a ratio rose on day six to 0.99 indicating that at the end of the 2nd drying cycle the ability of the mesophyll to fix CO_2 was significantly reduced. For the non-irrigation treatment the C_i/C_a ratio started to rise from day four and reached a peak on day seven, following irrigation, for the variety Jitlee. For R134, the peak C_i/C_a ratio occurred on day 5 (1.56) falling to 1.08 on day seven.

4.4 Discussion

Rambutan's have long been considered sensitive to soil moisture deficits (Coronel 1983, Tindal, 1994). The data generated over the seven day trial period confirm this observation.

The soil moisture tension data indicated that distinct soil moisture patterns occurred under the various irrigation regimes. A range of soil moisture conditions existed from field capacity to near the limit of soil tensions measurable with tensiometers (-0.08 to -0.09 MPa) with two stress/non-stress cycles of varying durations in between.

There were few differences in plant water status, as indicated by Ψ_L and RWC, and physiological measures such as A and g_s , between plants watered daily and second daily. Although, in 2nd daily irrigated treatments, soils tensions at 15 cm reached between -0.04 to -0.06 MPa on the morning of the second day following watering, there was no significant change in plant water status as indicated by leaf water potential and relative water content. Leaf photosynthesis and accompanying measurements also suggests that these parameters were not greatly affected by mild levels of soil moisture deficit over the duration of the experiment. High levels of available water at 40 cm appeared to be able to satisfy the plant requirements under a 2nd daily irrigation cycle.

Irrigating every third day resulted in high soil tensions at both 15 and 40 cm depths, on the third day following irrigation, particularly for the cultivar Jitlee. Measurements of Ψ_L and RWC at dawn were not significantly different from daily irrigated plants. However, A fell, sharply for R134, over the initial three day drying cycle and only recovered marginally on the day following re-watering. For the cultivar Jitlee, A had fallen to zero at the end of the second drying cycle whereas for R134 A was maintained at a low level ($3.7 \mu\text{mol m}^{-2}\text{s}^{-1}$). Jitlee was able to maintain a significant positive carbon budget during the 1st drying cycle, and showed little change during the 1st cycle. However, during the 2nd drying cycle, the rate of photosynthesis showed a dramatic decline to zero on day 5. In contrast, R134 showed the opposite pattern. On the 1st cycle a significant decline in photosynthesis occurred (from 11.8 to $2.8 \mu\text{mol m}^{-2}\text{s}^{-1}$) between the 1st and 3rd day. There was minimal change in the rate of A during the second cycle. On day seven following re-watering, A recovered in Jitlee whereas for R134 it dropped to near zero.

In non irrigated trees the decline in A over time was similar. Both cultivars were producing negligible amounts of assimilates by the morning of day four. On day seven following re-

watering of the non watered trees, A recovery occurred in R134 whereas for Jitlee A dropped below zero. In the non-irrigated treatment soil tensions at both depths reached a peak on day four, indicating a lack of readily available moisture. Dawn Ψ_L reached a minimum on day five for both cultivars and increased thereafter. This increase in Ψ_L is not readily explainable, except to say that leaves selected for the pressure bomb at this stage were wilted and colour changes (greying) indicated permanent wilt had begun to occur (Plate 2). Such extreme damage may have given rise to erroneous Ψ_L readings with the pressure bomb. Visual symptoms of wilt occurred on day 3 for Jitlee and day 4 for R134. Severe wilt and leaf colour change occurred for both cultivars on day 5 and 6. Following the completion of the experiment, all trees of both cultivars lost all their leaves; a reflection of the severity of the drought, despite a far from excessively low Ψ_L . Recovery occurred (new shoots) 7-14 days following rewatering. RWC dropped below 90% on day 4 and day 5 for Jitlee and R134 respectively. Both varieties reached a minimum RWC of 78% on day 6. Following rewatering the leaf RWC for the cultivar R134 recovered, whereas there was little change in Jitlee; further indicating the extent to which permanent damage had occurred by this stage.

Net CO_2 assimilation and related parameters appear to be a more sensitive indicator of plant response to changes in soil moisture than traditional measurements of plant water status after wilting occurs.

The C_i/C_a ratio is an indicator of photosynthetic capacity and conductance (Lauer and Boyer, 1992). Ratios greater than those experienced by well watered plants indicate that chloroplast dysfunction has occurred and assimilation of carbon is much reduced. Eventually, as the stomates close and assimilation falls to zero or less, internal leaf CO_2 levels rise above external levels. The rise in C_i/C_a appears to be associated with leaf wilt symptoms. For the non-irrigated treatment, the C_i/C_a ratio began to rise above 0.8 from day 4 for both cultivars. In the cultivar Jitlee, the C_i/C_a rose above 0.8 on day 6 in association with visual leaf wilting symptoms. The initial decline in A is associated with stomatal closure, but, when plants wilt, mesophyll conductance declines as indicated by the rise in C_i/C_a . If mesophyll conductance did not decline we would expect C_i to decline once stomata closed.

In conclusion, the rambutan appears to be highly sensitive to declining soil moisture. It lacks significant adaptive strategies, such as a highly sensitive conductance, and responds by large scale leaf loss in the face of soil drying. Similar observations on the time to onset of wilt have been observed in established mature field grown plants (Ramsay pers. com 1992). The response of rambutan to soil moisture deficit is similar, but occurs much faster, than that found in its relative *Litchi chinensis* where leaf conductance exhibits a continuous, but decreasing decline as Ψ_L declines (Menzel and Simpson, 1986). Prolonged periods between irrigations (2-3 days) in the field, although not resulting in visible damage to plants, could result in significantly reduced rates of photosynthesis and hence plant productivity. Soil-plant water interactions in the field, are somewhat more complicated than those that occur in a pot, although, the large size of the pots (200 L) and the similarity in reaction time to water shortages with those which occur in the field, suggest that the results generated are applicable to field grown plants.

Watering frequency of orchards will depend on a number of factors; eg. plant density, plant age, plant phenology, soil type and season. Data from this trial suggest that the frequency between irrigations should be minimised, particularly during active growing and/or fruiting stages.

4.5 References

- Coronel, R.E. (1983). Rambutan *in*: Promising fruits of the Philippines. University of Philippines, Los Banos.
- Lauer, M.J., and Boyer, J.S. (1992). Internal CO₂ measured directly in leaves. Abscisic acid and low leaf water potential cause opposing effects. *Plant Physiology*, 98:1310 -1316.
- Lok, J., (1988). The use of tensiometry in irrigation scheduling. in Proceedings of the Fourth International Micro-Irrigation Congress. Volume 2, October 23-28, 1988. Albury-Wodonga, Australia.
- Menzel, C.M., and Simpson, D.R. (1986). Plant water relations in Lychee: diurnal variations in leaf conductance and leaf water potential. *Agricultural and Forest Meteorology*, 37:267-277.
- Scholander, P., Hammel, H.T., Bradstreet, E.D., and, E.A. (1965a). Sap pressure in vascular plants. *Science*, 148: 339 -346.
- Tindall, H.D. (1994). Rambutan cultivation. F.A.O. Plant Production Paper 121, Rome, Italy.
- Watson, B.J. (1984). Rambutan (*Nephelium lappaceum*) in Tropical Tree Fruits of Australia. Editor: P.E. Page. Horticulture Branch, Queensland Department of Primary Industry.



Plate 1. Rambutan trees of two cultivars (Cv. Jitlee and R134) grown in 200 L pots.



Plate 2. Permanent wilting of rambutan leaves following five days without irrigation. Complete leaf drop occurred within the following fortnight.

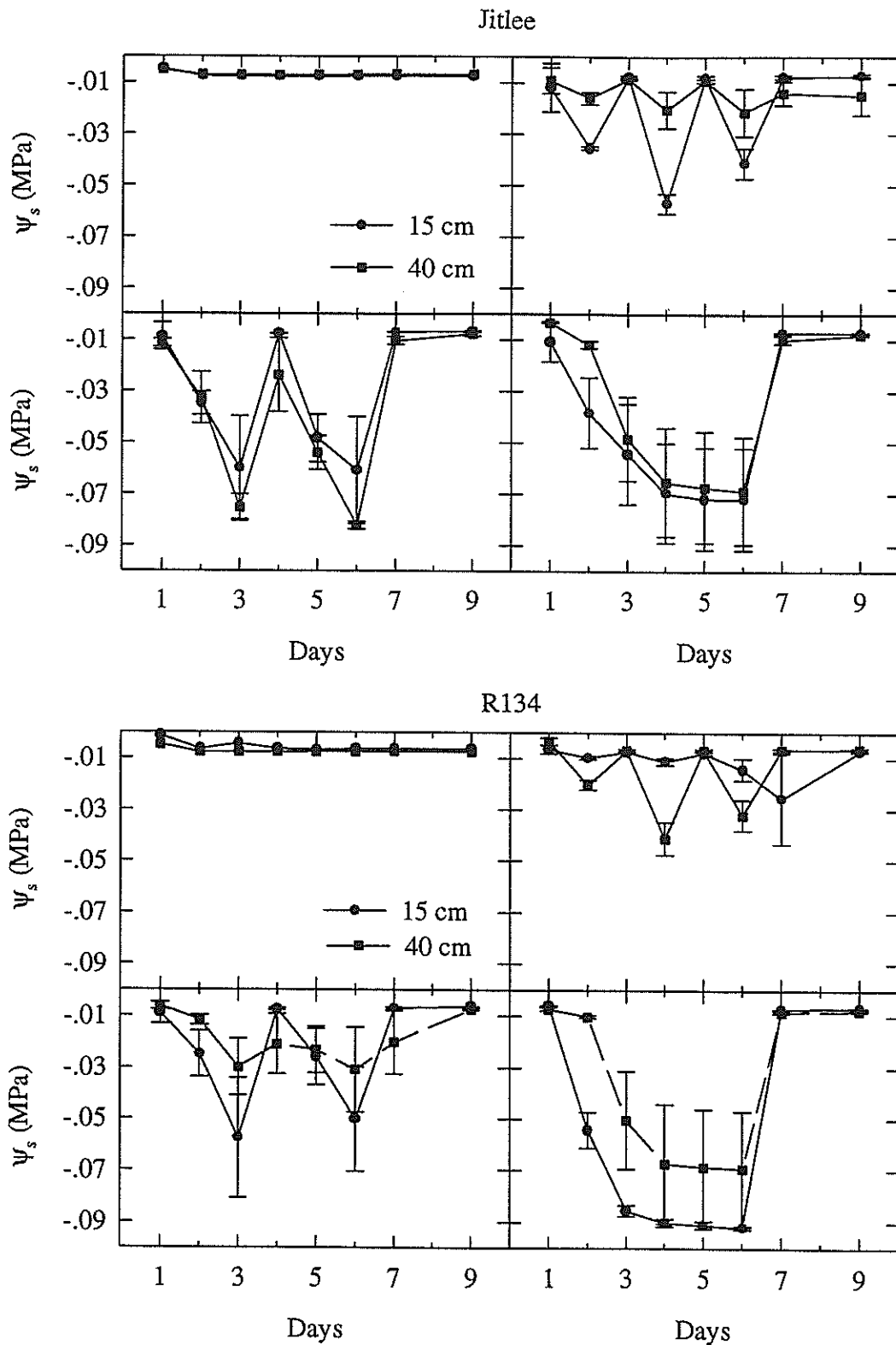


Figure 11. Soil moisture tension ($-\Psi_s$, MPa) obtained under four irrigation regimes for rambutan cultivars Jitlee and R134. Vertical bars indicate \pm standard error.

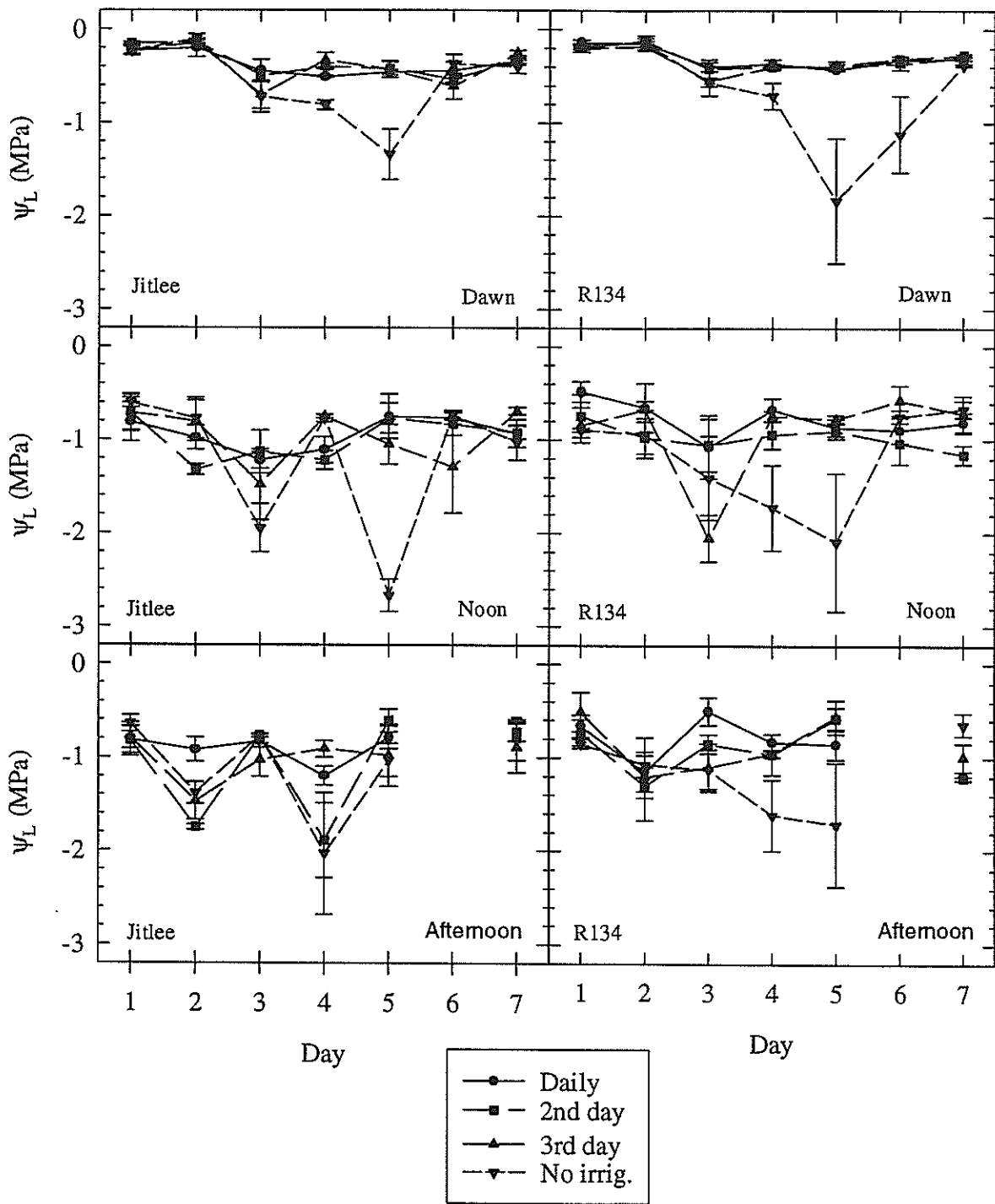


Figure 12. Leaf water potentials (Ψ_L , MPa) at dawn, noon and afternoon for cultivars Jitlee and R134 grown under four irrigation regimes. Vertical bars indicate \pm standard error.

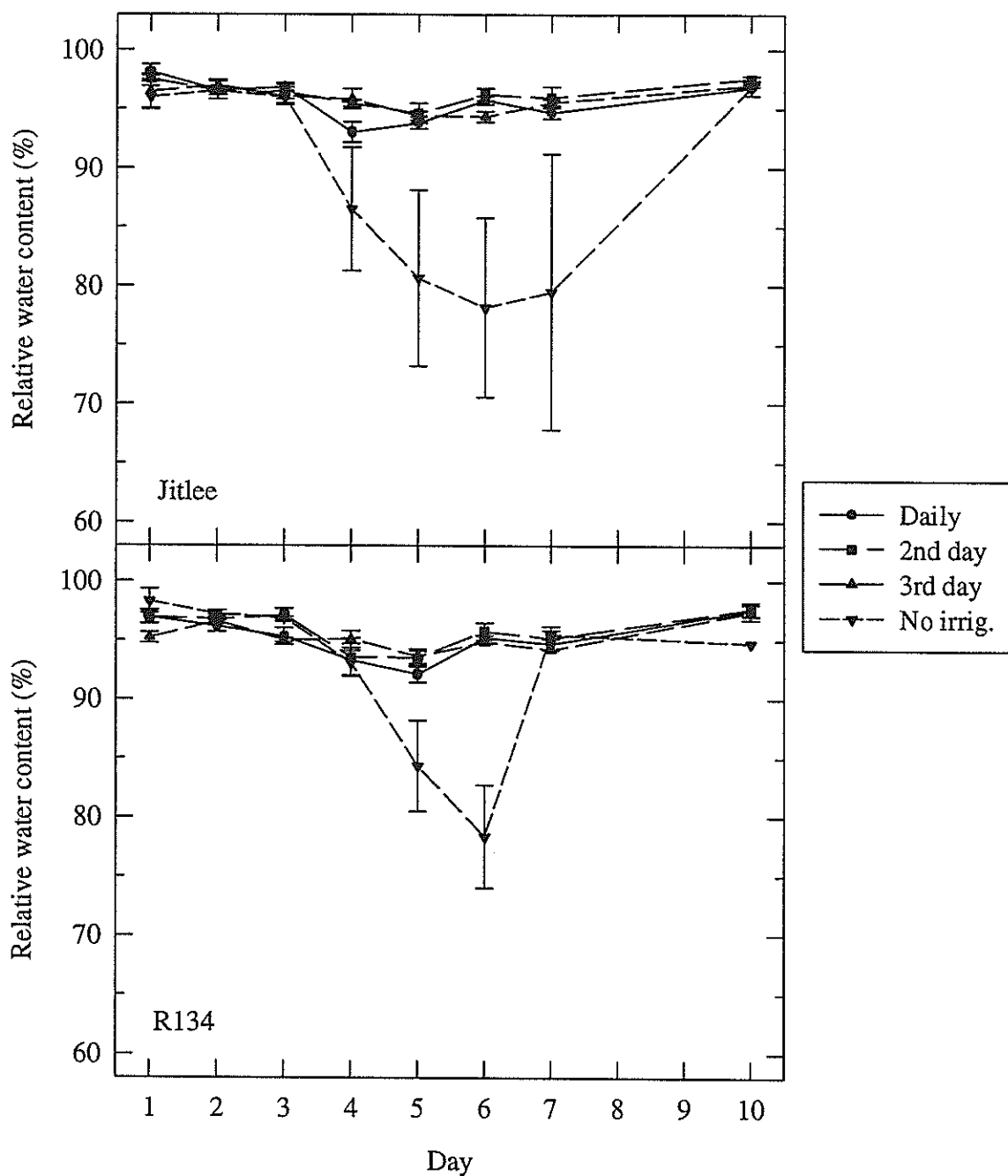


Figure 13. Relative water content (%) at dawn for rambutan leaves (cv. Jitlee and R134) grown under four irrigation regimes. Vertical bars indicate \pm standard error.

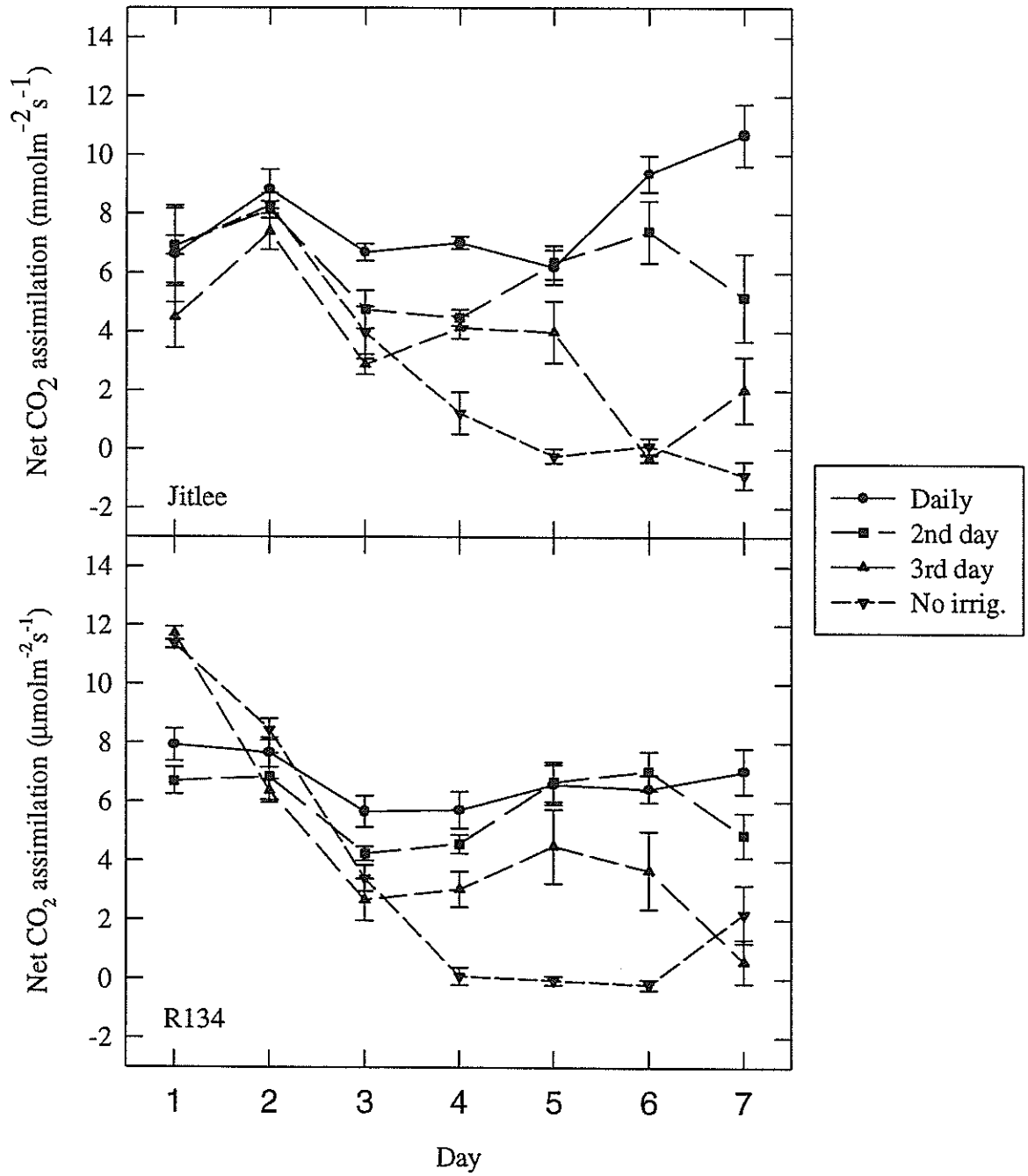


Figure 14. Net CO₂ assimilation (0900 - 1030 hours) for cultivars Jitlee and R134 grown under four irrigation regimes. Vertical bars indicate ± standard error.

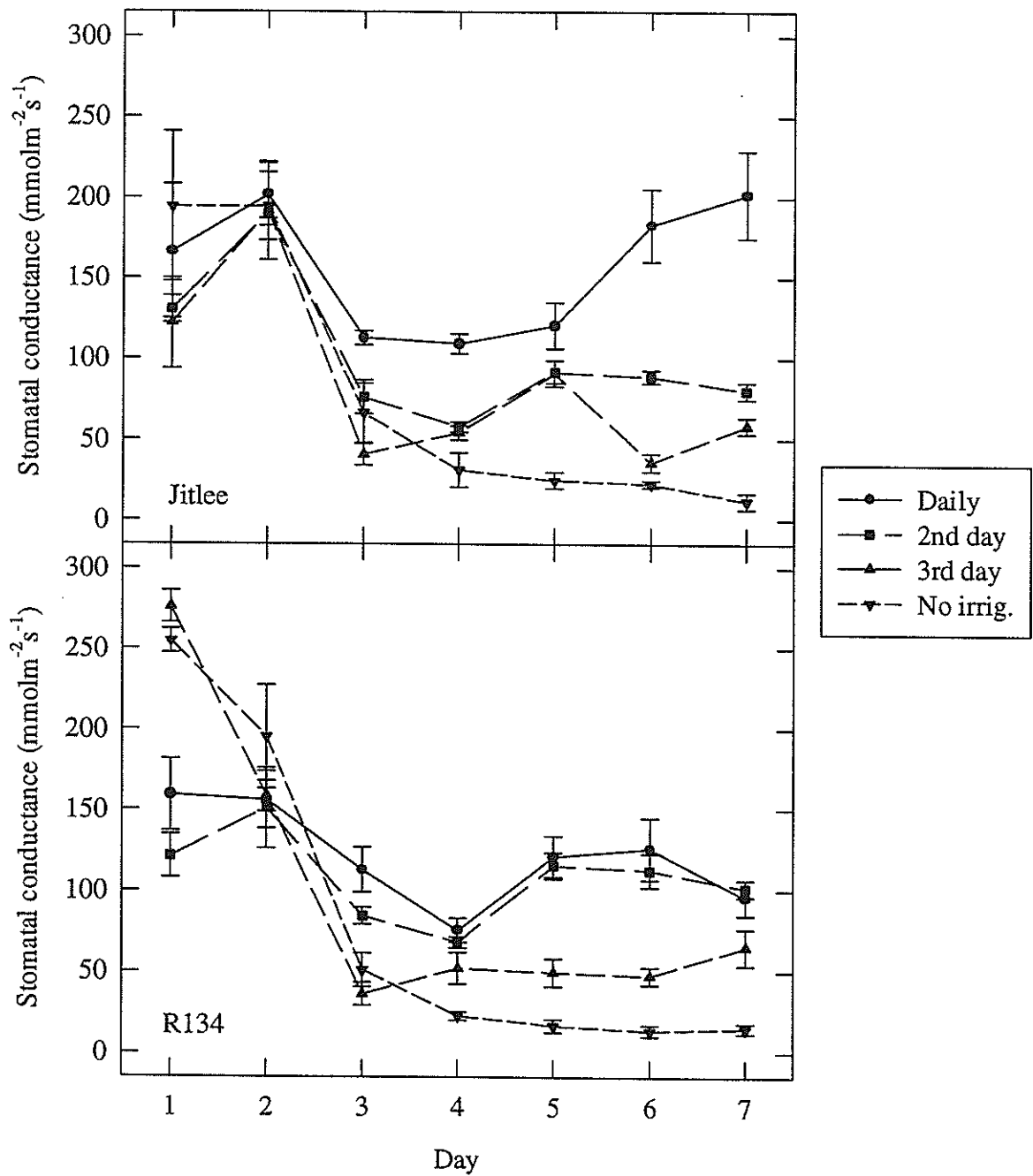


Figure 15. Stomatal conductance g_s (0900 - 1030 hours) for cultivars Jitlee and R134 grown under four irrigation regimes. Vertical bars indicate \pm standard error.

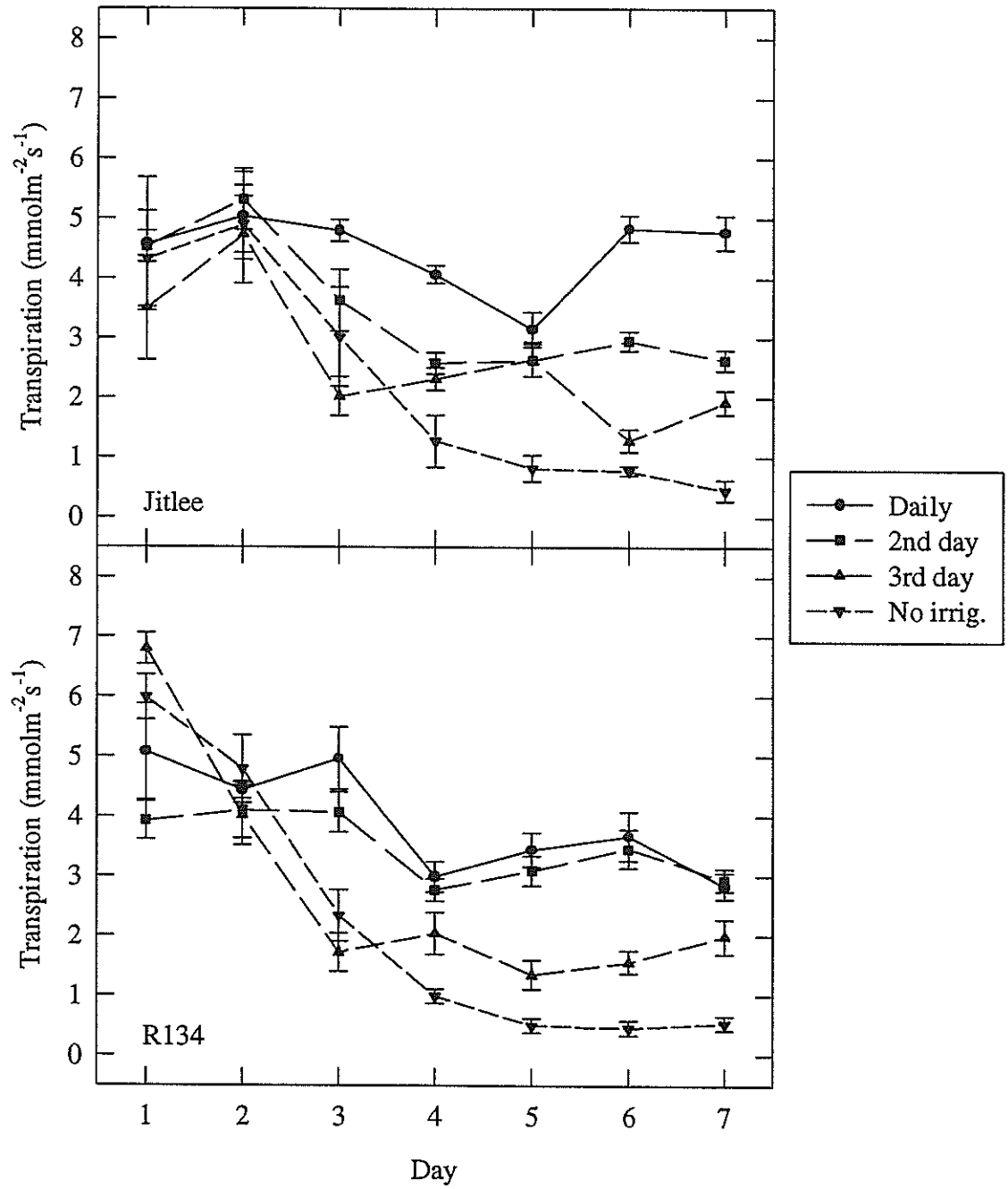


Figure 16. Transpiration, E (0900 - 1030 hours) for cultivars Jitlee and R134 grown under four irrigation regimes. Vertical bars indicate \pm standard error.

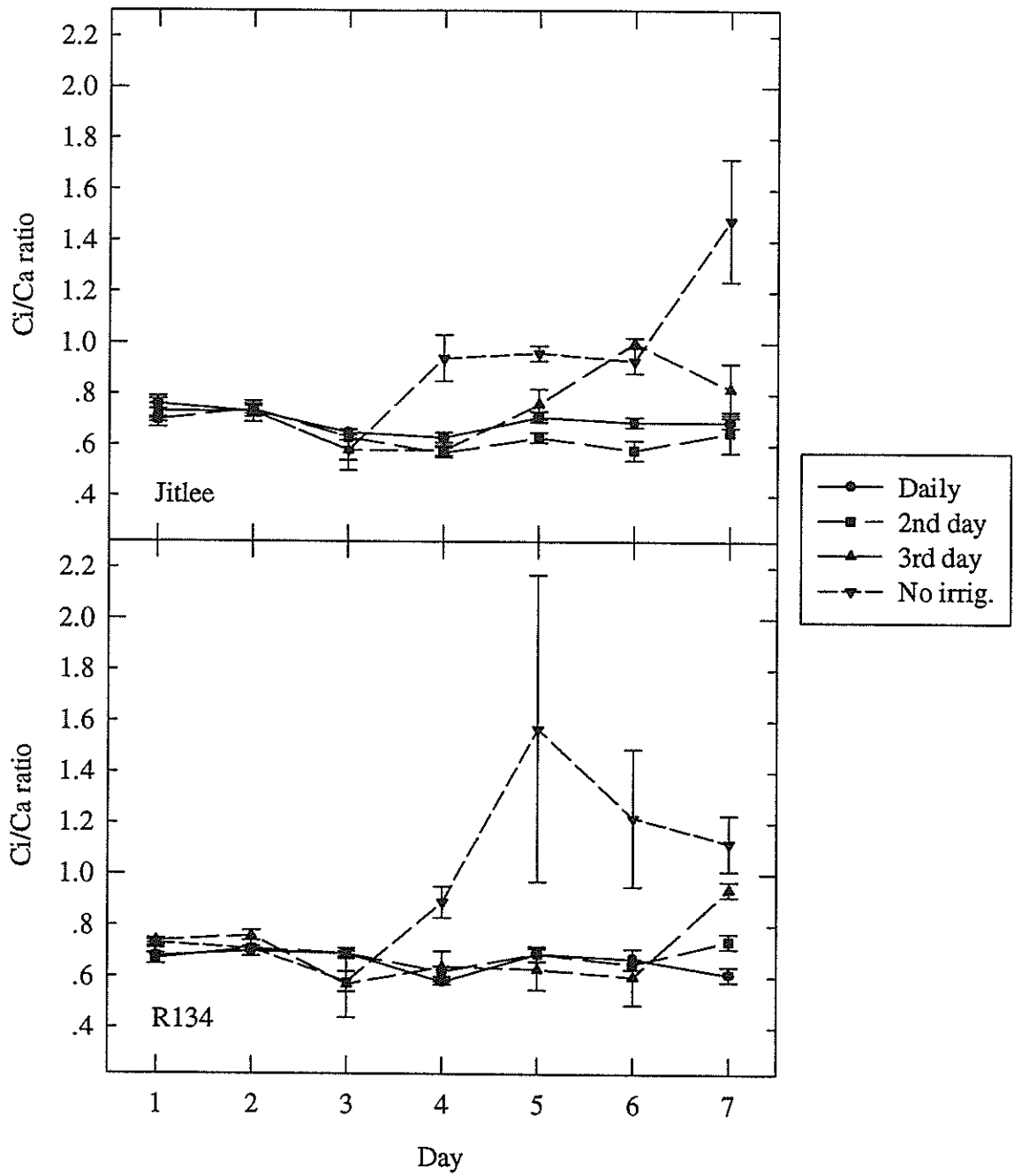


Figure 17. Change in Ci/Ca ratio (0900 - 1000 hours) over the seven day trial period for cultivars Jitlee and R134 grown under four irrigation regimes. Vertical bars indicate \pm standard error.

5.0 Photosynthesis and leaf water potential of irrigated and droughted mature field grown rambutan trees.

Y. Diczbalis, P. Watson and M. Chisholm

5.1 Introduction

In the Northern Territory irrigation management is crucial to the production of high yielding and high quality rambutan fruit.

Work conducted as part of this study has shown that pot grown rambutan trees are sensitive to water stress. The rapid response to soil water deficit in the pot grown plants may have been due to the restricted root zone and soil volume in the pots. The objective of the work reported in this chapter was to confirm the response of rambutan to soil moisture deficit in mature field grown trees

5.2 Materials and Methods

The experiment was conducted during the early dry season of 1994 to test the response of ten year old trees to soil moisture deficit. The trial was conducted on two trees of the cultivar Jitlee in the orchard at Berrimah Agricultural Research Centre. The small unreplicated nature of the trial was due to the unavailability of larger numbers of mature trees on the research farm and the reluctance of growers to participate in a trial where their trees could be injured by excessive soil moisture deficit.

Measurements of net CO₂ assimilation (A) and stomatal conductance (g_s) were made during the mid morning from 0930 to 1100 h using a Licor 6200 portable photosynthesis unit. One tree received daily irrigation and the other received no irrigation until minor leaf wilting occurred on day nine. Concurrently leaf water potential (ψ_L) measurements were made using a Soil Moisture Corporation pressure bomb. Ten replicate measurements were made on each tree. The data is presented as treatment means and standard error for comparisons of means. Recovery measurements following re-irrigation of the nil irrigated tree were not carried out as equipment was unavailable.

Soil moisture was monitored using an electrical capacitance system (EnviroScan[®]). Eight weeks prior the dry down two probes per tree, with sensors placed at 10, 20, 30, 40, 50, 70, 90 and 110 cm depths, were placed within 1.5 m of the trunk and 1.0 m of the sprinkler. Soil volumetric moisture was logged hourly during the project. The soil moisture data at 9.00 am is presented as means only.

5.3 Results

5.3.1 Stomatal Conductance

Stomatal conductance of the nil irrigated tree varied from 120 to 180 mmol m⁻² s⁻¹ for the first three days following cessation of irrigation and was similar to the values obtained in the fully irrigated tree. The g_s declined, from day four, three days after the cessation of irrigation and continued to do so until the cessation of measurements on day nine (Figure 18). On the last

day of measurements the mean g_s values for the irrigated and non irrigated trees were 122 and 26 $\text{mmol m}^{-2} \text{s}^{-1}$ respectively. The fall in g_s suggests that stomata were closing in response to increasing soil moisture deficit.

5.3.2 Net CO₂ assimilation (A)

Net CO₂ assimilation followed a similar pattern to that for g_s (Figure 18). Values for both the irrigated and non irrigated trees varied from 7.65 to 9.31 $\mu\text{mol m}^{-2} \text{s}^{-1}$ for the first four days of measurements. From day five A of the nil irrigated tree declined sharply in line with the decline in g_s . On the last day of measurements the mean A rates for the irrigated and nil irrigated tree were 8.35 and 2.26 $\mu\text{mol m}^{-2} \text{s}^{-1}$ respectively.

5.3.3 Leaf water potential (ψ_L)

Leaf water potential measurements, carried out concurrently with photosynthesis measurements, showed that ψ_L for the nil irrigated tree was significantly lower than that of the irrigated tree from day five (Figure 18). The overall mean ψ_L for the two treatments, although significantly different, was not greatly different, being -1.52 and -1.62 MPa for the irrigated and nil irrigated trees respectively. The pattern of change in ψ_L over time was not consistent with the A and g_s data because the ψ_L of the nil irrigated tree did not continue to decline following day four. The lowest potential reached was -1.9 MPa on day nine following which the nil irrigation treatment ceased. Irrigation was recommenced as the tree was showing minor symptoms of leaf wilting during the heat of the day.

5.3.4 Soil Moisture

The electrical capacitance data showed that uptake of moisture in the nil irrigated treatment occurred principally within the top 30 cm of the soil profile with reduced uptake occurring at 40 and 50 cm (Figure 19). There was no water uptake at 70 cm and below over the duration of nil irrigation. There was little to no variation in soil moisture with time and depth for the daily irrigated treatment.

5.4 Discussion

There is a lack of information on the effect of drought (nil irrigation) on water relations and tree growth in rambutan and tropical fruit generally. Our data shows that rambutans are extremely susceptible to drought and that visual symptoms of drought (leaf wilting) will occur within 8 days of nil irrigation. Leaf water potential and photosynthesis measurements are affected within four days of the commencement of nil irrigation. The rapid decline in g_s and A following the commencement of nil irrigation in mature field grown trees emphasises the susceptibility of rambutan to soil moisture deficit. The experimental data is supported by anecdotal evidence from NT growers who have found that mature trees can suffer severe leaf loss from 5-10 days following the breakdown of irrigation delivery systems.

5.4.1 Soil moisture extraction

The soil moisture data collected shows that uptake of moisture in the nil irrigated treatment occurred principally within the top 30 cm of the soil profile with reduced uptake occurring at

40 and 50 cm. There was no water uptake at 70 cm and below over the duration of nil irrigation. In contrast Menzel *et al.* (1994) found that lychees exposed to a long drought cycle in sandy soils were able to extract water to 1.5 m.

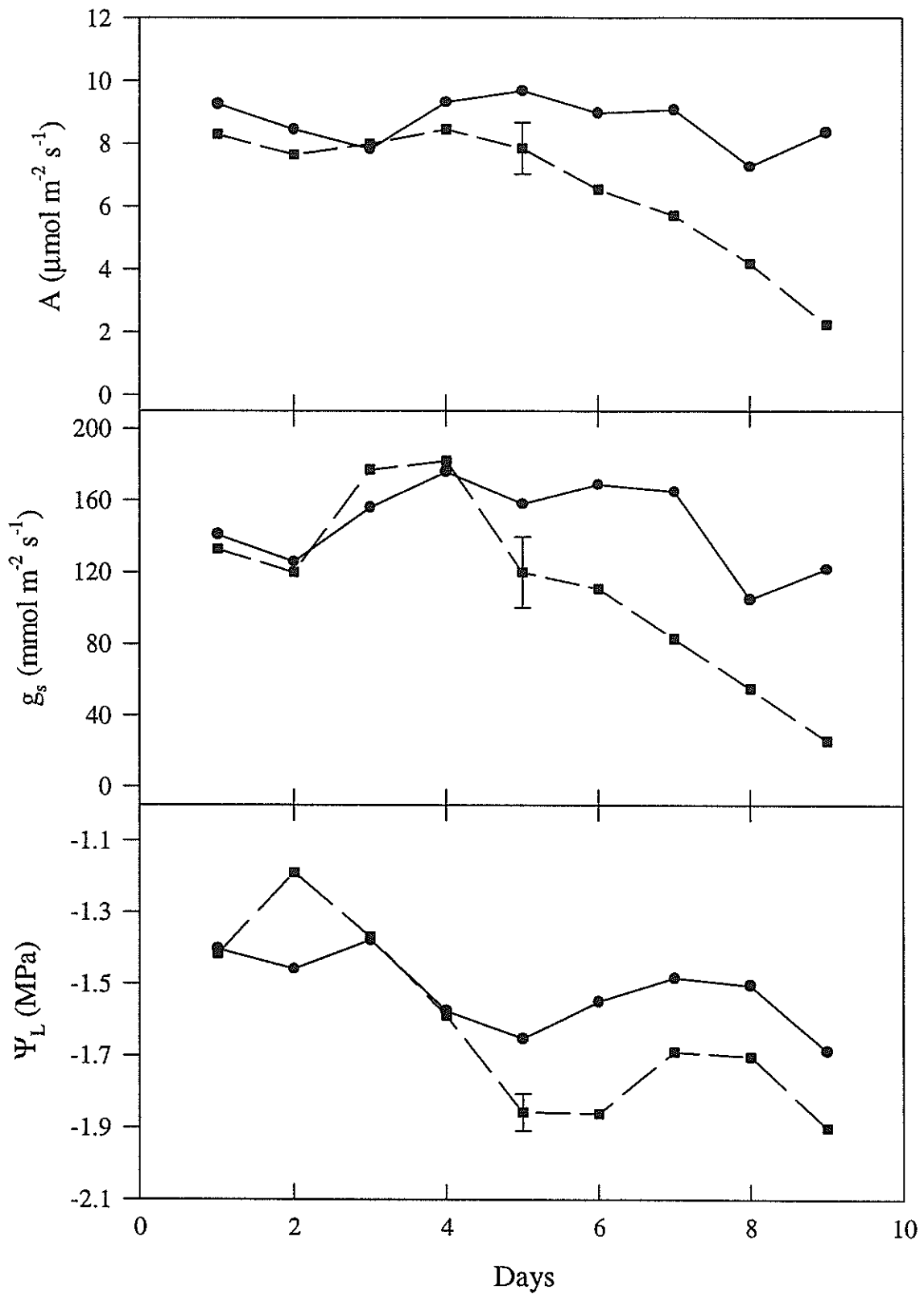


Figure 18. Net CO₂ assimilation (A), stomatal conductance (g_s) and Leaf water potential (ψ_L) of irrigated (solid line) and non irrigated (dotted line) mature rambutans. Irrigation for the non irrigated treatment ceased following day 1. Each point is a mean of 10 samples. The SE for comparison of means is indicated by the vertical bars ($P < 0.05$).

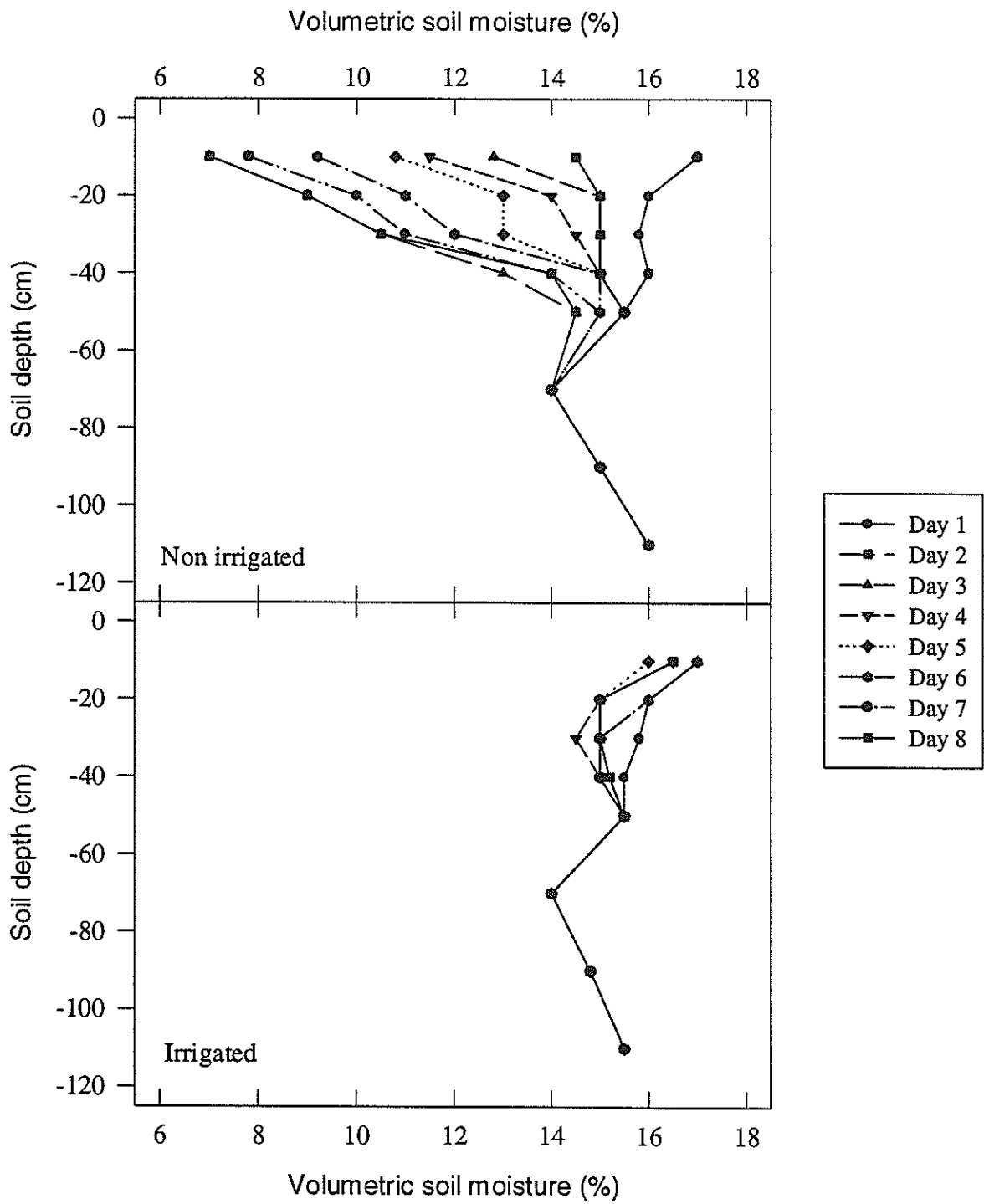


Figure 19. Volumetric soil moisture % of nil irrigated and irrigated rambutan trees.

5.4.2 Photosynthesis

In the irrigated tree the average A over the 9 day measurement period was $8.68 \mu\text{mol m}^{-2} \text{s}^{-1}$ which is similar to that found in a range of tropical species. Stomatal conductance ranged from 110 to $180 \text{mmol m}^{-2} \text{s}^{-1}$ throughout the measurement period. In the nil irrigated tree A fell from 8.29 to $2.26 \mu\text{mol m}^{-2} \text{s}^{-1}$ while g_s fell from 180 to $30 \text{mmol m}^{-2} \text{s}^{-1}$. These range in values are similar to those found in lychee by Menzel *et al.* (1994) with the difference being that the lower values found in droughted trees took at least 8 weeks to develop from the cessation of irrigation.

5.4.3 Leaf water potential

The minimum leaf water potential observed in the nil irrigated treatment was -1.9MPa on day nine. Whereas that observed in the irrigated treatment was -1.7MPa on day five. Early symptoms of leaf wilting was observed in the non irrigated treatment on day 9 when the maximum ψ_L was reached. There appears to be little difference between ψ_L of well irrigated plants and stressed plants prior to the onset of visual stress symptoms in rambutan. The ψ_L at which wilting occurs in rambutan is high when compared to other fruit tree species. In lychee, a relative of rambutan, ψ_L of -2.5MPa have been observed in droughted trees without any associated leaf wilting symptoms (Menzel *et al.* 1994). What's more this level of ψ_L was only reached following 16 weeks of nil irrigation on relatively sandy soils. Pongsoonboon (1991) found that in potted mangoes permanent leaf wilting does not occur until 36 days after nil irrigation and ψ_L reaches -3.5MPa . In species such as orange and macadamia ψ_L falls to -6.6 and -5.0 before permanent wilting occurs (Fereres *et al.* 1979; Stephenson *et al.* 1989).

5.5 Conclusions

Our data suggests that in the NT growing environment, potentially lethal levels of ψ_L are rapidly reached in rambutan following the onset of nil irrigation. Soil moisture monitoring shows that the bulk of soil moisture is withdrawn from the shallow soil horizons (0-40 cm). The information collected has important implications for irrigation scheduling of commercial rambutan orchards.

5.6 References

- Fereres, E., Cruz-Romero, G., Hoffmann, G.J., and Rawlins, S.L. (1979). Recovery of orange trees following severe water stress. *Journal of Applied Ecology*. 16:833-842.
- Menzel, C.M., Oosthuizen, J., Roe, D., and Doogan, V. (1994). The response of lychee to drought. Internal Report, Queensland Department of Primary Industries.
- Pongsomboon, W. (1991). Effects of temperature and water stress on tree growth, flowering, fruit growth and retention of mango (*Mangifera indica* L.). Ph.D. Thesis, Kasetsart University, Bangkok, Thailand.
- Stephenson, R.A., Ko, H.L., and Gallagher, E.C. (1989). Plant water relations of stressed, non-bearing macadamia trees. *Scientia Horticulturae*. 39:41-53.

6.0 Root distribution of rambutan growing in the wet/dry tropics of northern Australia.

Y. Diczbalis, P. Watson and P. Albano

6.1 Introduction

Rambutan, native to Sumatra and West Malaysia (Watson 1984), is an evergreen tree and a member of the Sapindaceae family and is related to longans and lychees.

The crop is being grown commercially for fresh fruit production in the top-end (12 - 14°S) of the Northern Territory, Australia. The wet/dry tropical climate is different from the wet tropics the plant experiences in its native environment. Cultivation of the crop in the top-end relies on the use of irrigation during the dry months of the years (April - October) and during dry periods experienced during the wet season (November - March) (Mollah 1986). In the Darwin area, on average evaporation exceeds rainfall, for eight months of the year.

Rambutan has been reported to be sensitive to drought (Coronel 1983) and irrigation is required particularly in growing environments where a distinct dry season exists. Experience gained by growing the crop in the NT suggest that mature established trees wilt within five to seven days of an irrigation, hence, irrigation frequencies are generally no longer than every third day and in the majority of orchards the crop is irrigated on a daily or second daily basis, particularly from flowering to harvest (July - December). Tindall (1994) reports that rambutans are considered shallow rooted with a main tap root which extends down several metres. He reports that no research on root distribution has been carried out. Root studies conducted on lychee suggest that the majority of roots are in the top 30 - 40 cm (Roy *et al.* 1987 and Menzel *et al.* 1990). However, Menzel *et al.* (1994) report that lychee has the ability to withstand long periods of drought and can extract water from depth (120 to 150 cm).

Improved irrigation management of the crop requires more detailed knowledge of root distribution. This paper reports on the root distribution of rambutan, grown in three orchards in the top-end of the Northern Territory.

6.2 Materials and Methods

Three commercial rambutan orchards in the Darwin (12°S 132°E) area, were selected for the root sampling procedure, which occurred during December 1992. Trees selected were 4-6 years old and comprised a number of cultivars (Rongrien, Gulah Batu, Chompoo and Jitlee). They were grown at 5-8 m intervals in rows 8-10 m apart (equivalent to a density of 156-200 trees/ha). Trees in all orchards were managed as commercial crops with respect to nutrition, weed management and leaf litter mulch. The trees in orchards 1 and 2 were irrigated daily. Trees in Orchard 3 were irrigated every 3rd day. In all cases the area under the tree canopy was free of weeds and the inter-rows were grassed.

6.2.1 Sampling

At each orchard three trees were selected. Samples were taken at five horizontal distances from the trunk (50, 100, 150, 200 and 300 cm) and five depth (5, 15, 30, 60 and 120 cm) at three positions, 120° intervals around the tree. Position one was in line with the microsprinkler and positions 2 and 3 were located clockwise from one. Following removal of leaf mulch soil and root samples were taken using Eijkelkamp® bulk density sampling equipment. Sample tubes 100 cc in volume were driven into the soil/root matrix at the required sampling point. Samples were kept in a cold room at 5°C for two months until processing. Samples were wet sieved to separate root and soil, roots were then dried at 70°C for 48 hours and dry weights recorded. Root density was expressed as (g) dry weight per 100 cc. Data is presented per farm as means of nine sampling sites with associated standard error and total farm means (of 27 samples) and associated standard errors

A separate sampling was carried out for bulk density measurements. Samples were taken, using the Eijkelkamp® bulk density sampling equipment at 5, 10, 20, 30, 40, 50, 60, 80, 100 and 120 cm under each of the 3 tree at each orchard. After removal of the leaf mulch a single sample was taken per tree at a site half way between the trunk and the tree canopy edge. Samples were dried at 105°C for 48 hrs and weighed. Bulk density is expressed as g/cm³. Data is presented per farm as means and associated standard errors of three sites.

6.3 Results

6.3.1 Root distribution with depth and distance from trunk

In all orchards root recovery declined rapidly with depth and increasing distance from the trunk (Figure 20). There were differences in root density between farms, particularly at 5 cm depth. At 5 cm depth the highest root density of 2.1 g/100 cm³ was obtained on farm 2 and the lowest on farm 1. Mean results for all farms shows that the bulk of roots sampled were confined to the surface 5 cm of the soil profile and 100 cm from the trunk (Figure 21). Root densities are significantly higher at the 5 cm depth for horizontal distances out to 200 cm (Figure 21). At 300 cm from the trunk there are negligible roots at all depths. Root densities at depths lower than 5 cm only vary significantly at 50 cm from the trunk. At distances greater than 50 cm there is no significant variation in root density with depth. The percentage root density distribution is shown in Table 8. Farm three had a higher % of roots in the surface horizon (78.2 %) relative to the mean of 67.9 %. Farm three also had a greater percentage (25.3 %) of roots at 150 cm from the trunk than that which occurred at the other two farms (approx 12 %).

Table 8. Percentage rambutan root distribution on three farms (F1-3) at a range of depths and horizontal distances from the trunk.

Farm	F 1	F 2	F 3	Mean	Farm	F 1	F 2	F 3	Mean
Soil Depth (cm)	% of Sampled Roots				Distance from Trunk (cm)	% of Sampled Roots			
5	56.7	68.7	78.2	67.9	50	37.5	56.4	30.3	41.9
15	17.2	9.9	10.1	12.8	100	26.9	26.0	37.1	28.4
30	14.1	3	6.4	6.9	150	14.3	11.1	25.3	16.1
60	6.1	15.8	4.0	9.5	200	12.9	6.5	7.3	7.8
120	5.9	2.7	1.4	2.9	300	8.4	0	0	5.1

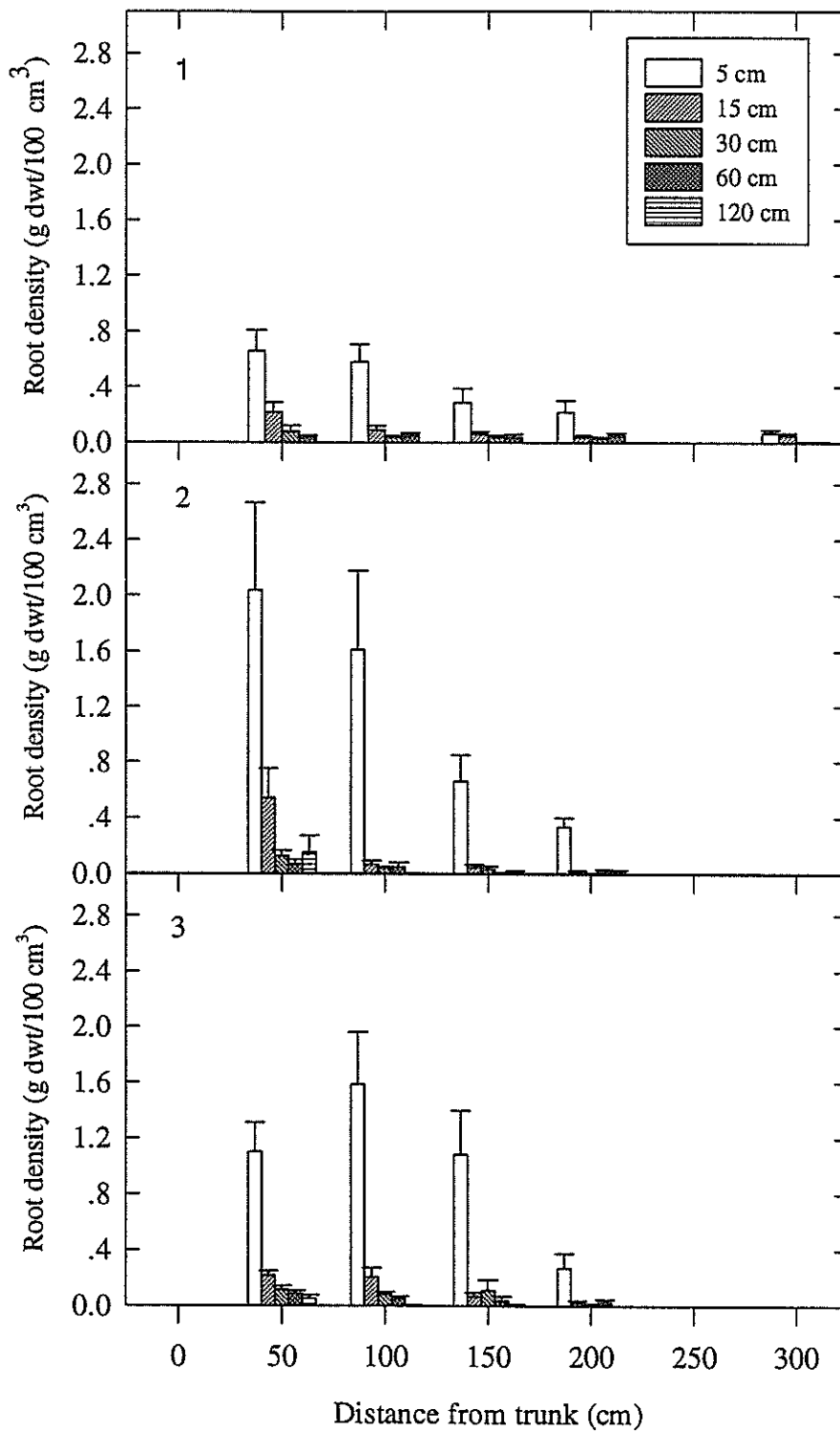


Figure 20. Mean rambutan root density (g dry wt./100 cm³) on three commercial farms at a range of depths and distances from the trunk. Data points are means of 9 samples. Vertical bars represent standard error.

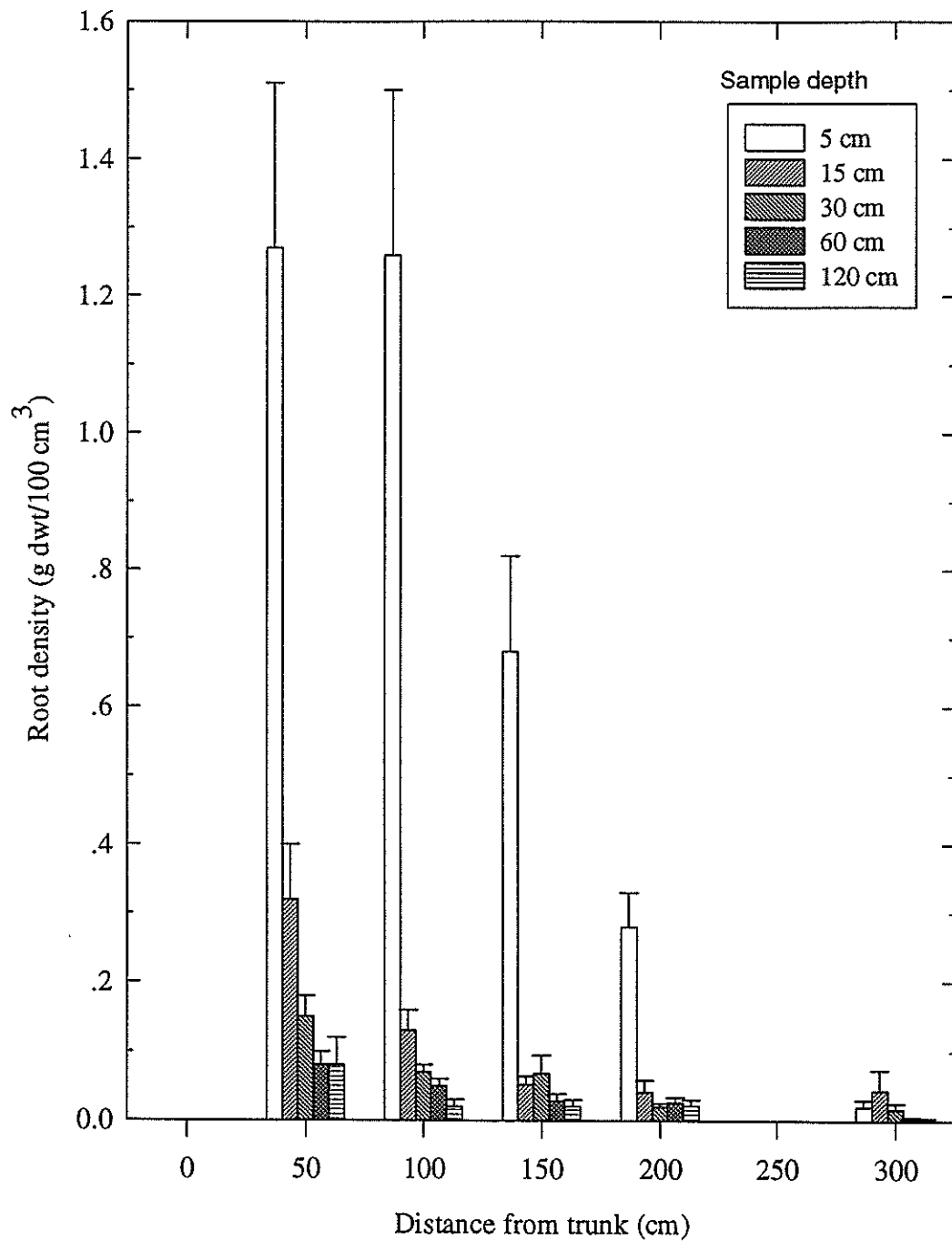


Figure 21. Mean rambutan root density (g dry wt./100 cm³) of three commercial farms at a range of depths and distances from the trunk. Data points are means of 27 samples. Vertical bars represent standard error.

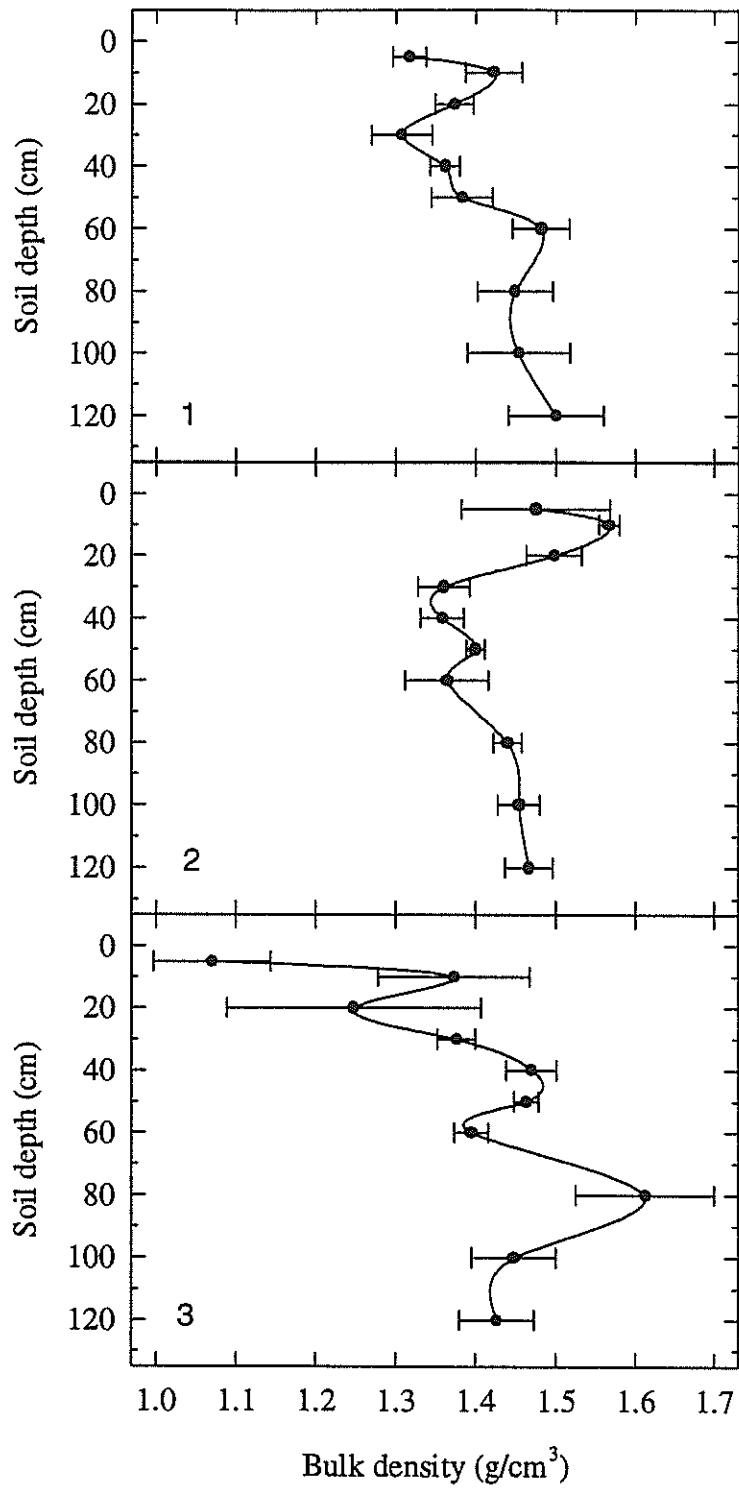


Figure 22. Soil bulk density (g/cm³) profiles for three rambutan orchards. Data are means of three samples and vertical bars represent standard errors.

Roots were not separated into different size groups, however, visual observations suggest that the bulk of roots greater than 2.0 mm in diameter were present in the surface horizon. Sampling sites were chosen to avoid the thick lateral roots (>10 mm) which run from the trunk, along the surface, out to the edge of the canopy.

6.3.2 Bulk density

Bulk density measurements varied with orchard and depth (Figure 22). The bulk density profile of orchards 1 and 2 were similar with variable densities in the surface horizons (5-30 cm) and a trend to increasing density with increasing depth thereafter. The density profile for orchard 3 was extremely variable with unusually low density at 5 cm and a high reading at 80 cm. Overall the density range was what would be expected for soil textures of sand loams at the surface to sandy clay loams with depth.

6.4 Discussion

The shallow nature of the root system in rambutan, is similar to that reported by Menzel *et al.* (1990) for lychee in South East Queensland. Roots were sampled during the mid to late fruit maturity stage, when it is expected that root system activity would be high. Because of the actively growing and flushing nature of rambutan (when water is available) root activity would probably be high throughout the year, except possibly for periods in which relatively low night temperatures occur (June - August). The results suggest that there was no significant difference in root density with depth, between farms, despite the less frequent irrigation pattern which occurred on farm 3. Root density at the three sampling locations around the tree did not vary significantly, indicating that proximity to the water source (microsprinkler) did not influence rooting patterns. Root density also appeared to be unaffected by differences in soil bulk density

Root density obtained were somewhat lower than those observed in an earlier sampling exercise (Diczbalis and Hamilton, 1992). In the previous report, single orchard data, suggested that root densities were as high as 5.0g/100 cm³ in surface soils. Data obtained from this exercise suggest that peak mean root densities are approximately 1.5g/100cc. Despite the variation which will exist between plants in various orchards the results indicate that rambutans are extremely shallow rooted and that the root system does not extend beyond the edge of the tree canopy (Plate 3). The surface nature of the roots may well restrict root activity to the cooler darker areas which occur under the canopy. Observation of root growth in rambutan suggest that where a significant mulch layer exists roots are found above the soil surface in the mulch layer.

The implications of the findings are that; irrigation and fertiliser application should be frequent and that the wetted area should be restricted to the area under the tree canopy. These results correspond with field observations which suggest that trees can wilt within five to ten days of nil irrigation.

6.5 References

Coronel, R.E. (1990). Rambutan in "Promising fruits of the Philippines". University of Philippines, Los Banos.

- Diczbalis, Y. and Hamilton, D. (1992) Rambutan - Root distribution investigations. Horticulture Branch, Technical Annual Report, 1990 - 1991. Northern Territory Department of Primary Industry and Fisheries Technical Bulletin No. 192.
- Menzel, C.M. et. al (1990). Root distribution of lychee trees growing in acid soils of subtropical Queensland. Australian Journal of Experimental Agriculture 30: 699-705.
- Mollah, W. (1986). Rainfall variability in the Katherine - Darwin region of the Northern Territory at some implications for cropping. The Journal of the Australian Institute of Agricultural Science, 52: 28-36.
- Roy, R.N. et. al.(1987). Studies on the feeder root distribution of litchi (*Litchi chinensis* Sonn.) cv. Bombai Indian Agriculturist 31: 33-41.
- Watson, B.J. (1984). Rambutan (*Nephelium lappaceum*) in 'Tropical Tree Fruits of Australia'. Editor: P.E. Page. Horticulture Branch, Queensland Department of Primary Industry.



Plate 3. An up rooted ten year old rambutan tree. This photograph clearly displays the surface nature of the root system.

7.0 Effect of shoot and root temperature on CO₂ assimilation and growth in rambutan

Y. Diczbalis and C. M. Menzel

7.1 Introduction

Rambutan (*Nephelium lappaceum* L.) is a member of the Sapindaceae family which includes the popular lychee (*Litchi chinensis* Sonn.) and longan (*Dimocarpus longan* Lour.). All are native to South-East Asia, with rambutan pantropical and lychee and longan subtropical (Verheij and Coronel, 1991). The environmental conditions for growth and cropping have been studied in lychee (Menzel and Simpson, 1994), but no information is available for the other species. The rambutan is grown in a number of locations outside its natural distribution including the greater part of South-East Asia, central America, Africa and more recently in northern Australia (Watson, 1988). The main producers are Indonesia, Malaysia, Thailand and the Philippines, with smaller industries in China, Taiwan, Vietnam, Burma, India, Hawaii, Australia and Puerto Rico. Generally, rambutans are grown from 0° to 17° latitudes, but most commonly within 12° and at elevations of up to 500 m within 8° of the equator (Verheij and Coronel, 1991; Yaacob and Subhadrabandhu, 1995). In its native environment, rainfall usually exceeds 2000 mm per year and is evenly distributed, while nights are above 20°C.

Vegetative growth in rambutan occurs as a series of leaf flushes which usually appear after harvest, on terminal branches which have not flowered and fruited the previous season. Flowers are normally borne on terminal inflorescences, although at times, a proportion of axillary inflorescences may also be initiated. The majority of cultivars in South-East Asia flower between April and July, and fruit between July and October, although sometimes there is a small crop between December and February (Almeyda *et al.*, 1979). In a monsoonal environment such as the Philippines, rainfall controls production, with leaf growth during the rainy season, and inflorescences during the dry season (Valmayor *et al.*, 1970), while in Indonesia where there is continuous rain, flowering is extended (Lam and Kosiyachinda, 1987). At higher latitudes such as Darwin in northern Australia (12°S), temperature dominates phenology in irrigated orchards, with flowering from June to August, and mature fruit from November to December (Y. Diczbalis, unpublished data). Mean daily minimums range from 19°C in July to 25°C in November, with days close to 32°C. Areas further south which experience nights below 15°C do not appear suitable for commercial production, since trees grow slowly, flower and set poorly and shed their leaves (Watson, 1988).

We report on the effects of night and root temperature on vegetative growth and physiology. The aims of the experiments were to characterise the vegetative response of rambutan to temperature. The results show that nights and roots below 22°C decreased growth by reducing CO₂ assimilation, whereas the changes in water, nutrient and carbohydrate status were relatively small.

7.2 Materials and Methods

7.2.1 Night temperature

Seedlings of rambutan cv Rapih were grown in 0.5 litre of soil in a screenhouse at Darwin, Australia (lat. 12°S). After 10 months, they were repotted into 8 litres of sand, peat and soil (2:1:1) and grown at Nambour (lat. 27°S) in a glasshouse with day/night cycles of 32°/28°C, with 20 g of dolomite (14% Ca and 11% Mg) and 7 g of superphosphate (9% P, 20% Ca and 10% S) added to each pot. After four months, the seedling were transferred to naturally-lit temperature-controlled glasshouses at 22°/14°, 32°/14°, 32°/22° or 32°/28°C (12 h days and nights), with RH during the day from 70 to 90%, and vapour pressure deficit (VPD) below 1.5 kPa. The plants were watered weekly with a one litre solution containing the following nutrients: (mM) N, 14; P, 2.4; K, 4.3; and (μ M) S, 20; Mg, 21; Mn, 4.5; Fe, 17.9; Zn, 0.8; Cu, 0.8; and B, 9.1, and given a foliar spray containing 0.2 g each of Mg, Zn and Cu per litre every second week.

A record was kept every one to two weeks of vegetative flushing in the trees and the number of flushes per plant. After 18 weeks, the seedlings were harvested for a record of the increment in stem extension, node and leaf production, leaf area (Li-Cor leaf area meter), and dry weight increase of leaves, stems and roots. The leaves, stems and roots were analysed for N, P, K, Ca, Mg, Cl, Mn, Fe, Cu and B (Menzel *et al.*, 1993) and for starch (Rasmussen and Henry, 1990). Data are the means of 11 or 12 plants per treatment and are presented with standard errors.

At weeks 15 and 18, measurements were made of leaf water potential (Ψ_L) with a pressure chamber, and net CO₂ assimilation rate (A) with a Li-Cor photosynthesis meter using a one litre curvette. Samples were collected from sun-lit leaves behind the new growth at 0830, 1000, 1200, 1400 and 1600 h. The effects of various periods of exposure to cool nights of 14°C and recovery of Ψ_L and A on transfer to warm nights of 28°C were also investigated in the last month of the experiment. Treatments were plants grown continuously at 32°/28° or 32°/14°C, and plants exposed to 32°/14°C for 5, 10 or 20 days before transfer to 32°/28°C on day 0. Measurements were taken at 1000 h over two days at the low temperatures (day -1, day 0) and the recovery after three days at the high temperature (day 1, 2 and 3). Data are the means of three (Ψ_L) or four (A) trees per treatment and are presented with standard errors.

7.2.2 Root-zone temperature

Seedlings of rambutan cv. Rapih were grown in 8 litres of sand, peat and soil in a heated glasshouse as described above, and after eight months, transferred to water baths at 15°, 20°C or 38° \pm 1°C. A set of plants was also maintained at ambient soil conditions which ranged from nights of 25°C to days of 32°C with an average of 28°C. There were six or seven plants per treatment, with only single water baths for each temperature. After 12 weeks, the seedlings were harvested as described above, with the data presented as treatment means with standard errors. In the week before harvest, diurnal measurements were made of Ψ_L and A over two days as described earlier.

7.3 Results

7.3.1 Night temperature

7.3.1.1 Plant growth:

Nights of 22° and 28°C compared with 14°C increased the number of flushes per plant, but reduced the duration of flushing (Table 9). Flushing was only slightly weaker with cool days of 22° than with 32°C when nights were 14°C. Stem extension, node and leaf production and leaf area increased with warm days or nights (Table 9; Plate 4). There was also an effect of temperature on the morphology of individual leaves, which were larger and thicker with nights at 22° and 28°C (Table 9). Total plant dry weight increased as the night temperature increased, but there was only a slight difference between 22°/14° and 32°/14°C (Table 10). This response was reflected by the changes in stem and root dry weight, whereas leaf dry weight increased with warmer days and nights. The larger plants grown at 22° or 28°C nights also allocated a greater proportion of dry matter to the shoots and less to the roots.

7.3.1.2 Tree water status and net CO₂ assimilation:

Leaf water potential (Ψ_L) at 22°/14°C was -0.8 MPa (SE = 0.01) during the day, whereas the plants at 32°/14°C were on average 0.3 MPa lower, and plants at 32°/22° and 32°/28°C an average of up to 0.7 MPa lower (Figure 23). Net CO₂ assimilation rate (A) was below 2.0 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at 22°/14°C, with no diurnal trend, while A in the other treatments followed the course of photon irradiance (PPFD) to reach peaks between 1000 and 1400 h (Figure 23). Averaged across the day, A was similar in the 32°/22°C and 32°/28°C treatments and about half in the 32°/14°C regime. The decline in CO₂ assimilation in the chilled plants was due to stomatal closure, with these plants having lower stomatal conductance (g_s) throughout the day (data not presented).

Average Ψ_L at 32°/28°C was -1.5 MPa (SE = 0.1), about 0.3 MPa higher in plants grown continuously at 32°/14°C, and about 0.5 MPa higher in plants grown at 32°/14°C for 5 to 20 days (Table 11). Since the data for the 5, 10 and 20 day treatments were similar, only the means of the 20 day treatment are presented. The water status of these treatments began to decline after transfer to warm nights (28°C) and approached the 32°/28°C treatment by day three. Average A in the 32°/28°C treatment was $8.2 \pm 1.1 \mu\text{mol m}^{-2} \text{s}^{-1}$, about a third in the 32°/14°C treatment, and close to zero in the other treatments before transfer (Table 11).

After three days, gas exchange recovered to about half the rate in the seedlings grown continuously at 32°/28°C.

7.3.1.3 Nutrient and starch concentrations:

The only nutrient that was consistently affected by temperature was N, which was lowest in the leaves (2.2 vs 3.2%) stems (0.7 vs 1.1%) and roots (0.8 vs 1.3%; max. SE = 0.1) of plants at 32°/28°C than in the other treatments. The effects of temperature on the concentrations of the other nutrients were generally small (data not presented). There was no consistent effect of temperature on the concentrations of starch in the leaves which were below 1.5%, whereas, stem and root starch were lower at 32°/28°C (Table 10).

7.3.2 Root zone temperature

7.3.2.1 Plant growth:

The two critical temperatures at which 90% of maximum growth occurred were about 23° to 32°C for stem extension, 20° to 29°C for node and leaf production, 23° to 31°C for leaf area and dry weight, 25° to 30°C for stem dry weight and 19° to 25°C for root dry weight (Figures 24 and 25). Since node and leaf production were similar across temperature, only the changes in the number of nodes are presented. The average size of leaves was $96 \pm 20 \text{ cm}^2$, $204 \pm 31 \text{ cm}^2$, $292 \pm 25 \text{ cm}^2$ and $145 \pm 32 \text{ cm}^2$ at 15°, 20°, 28° and 38°C, respectively, whereas there was no effect on specific leaf area (SLA) which was $148 \pm 4 \text{ cm}^2 \text{ g}^{-1}$. Warm roots also shifted the distribution of plant dry matter in favour of the shoots: shoot/root ratio was 4.2 ± 0.1 at 28° and 38°C and 2.5 ± 0.2 at 15° and 20°C.

7.3.2.2 Tree water status and net CO₂ assimilation:

Averaged across the day, Ψ_L was -1.5 MPa (SE = 0.1) at 20°C and 0.1 to 0.3 MPa lower at the other temperatures (Figure 26). Net CO₂ assimilation was below $2 \mu\text{mol m}^{-2} \text{ s}^{-1}$ at 15° and 38°C, with no obvious peak, whereas A in the other treatments followed the course of photon irradiance (Figure 26). Average A was $4.5 \pm 0.3 \mu\text{mol m}^{-2} \text{ s}^{-1}$ at 28°C, and 30% lower at 20°C with the greatest difference at 1200 h and the least at 1600 h. The decline in A in plants grown at extremes was associated with lower g_s than at 28°C (data not presented).

7.3.2.3 Nutrient and starch concentrations

Root zone temperature generally had only a small effect on tissue nutrient concentrations. The exceptions were leaf N (2.4 vs 2.8%; max SE = 0.1), leaf P (0.23 vs 0.30%; max SE = 0.01) and stem P (0.25 vs 0.32%; max SE = 0.01) which were lower at 28° and 38°C than at 15° and 38°C. The concentrations of starch were below 1.0% in the leaves, and about 40% higher in the roots than in the stems. In the stems, starch was higher at 28° and 38°C (7.4 and 8.5%) than at 15° and 20°C (3.1 and 3.7%; max. SE = 0.9), while in the roots, starch was only higher at 28°C (9.4% vs 7.0 to 7.7%; max. SE = 1.2).

Table 9. Effect of day/night temperature on shoot development in rambutan seedlings after 18 weeks (Exp. 1). Data are the means of 11 or 12 plants per treatment \pm standard errors

Day/night temperature	No. flushes per plant	Duration of flushing (weeks)	Stem extension (cm)	No. nodes per plant	No. leaves per plant	Leaf area (m ² per plant)	Single leaf area (cm ²)	Specific leaf area (cm ² per g)
32°/28°C	4.0 \pm 0.1	5.8 \pm 0.2	70 \pm 7	16.6 \pm 1.3	15.5 \pm 0.9	0.60 \pm 0.05	386 \pm 23	116 \pm 4
32°/22°C	4.0 \pm 0.1	6.0 \pm 0.2	50 \pm 5	12.3 \pm 0.9	12.0 \pm 0.8	0.45 \pm 0.05	366 \pm 24	112 \pm 4
32°/14°C	2.4 \pm 0.3	8.5 \pm 0.4	14 \pm 4	7.1 \pm 1.3	6.6 \pm 1.3	0.12 \pm 0.04	169 \pm 20	142 \pm 18
22°/14°C	1.6 \pm 0.2	12.5 \pm 1.3	5 \pm 1	3.5 \pm 0.4	3.3 \pm 0.4	0.04 \pm 0.01	147 \pm 22	171 \pm 16

Table 10. Effect of day/night temperature on increment in plant dry weight, shoot/root ratio, and on the concentration of starch (% dry weight) in the stems and roots of rambutan seedlings after 18 weeks (Exp.1). Data are the means of 11 or 12 plants per treatment \pm standard errors

Day/night temperature	Leaf (g per plant)	Stem	Root	Total	Shoot/root ratio	Concentration of starch (%)	
						Stem	Root
32°/28°C	52.8 \pm 5.0	9.4 \pm 1.6	13.7 \pm 2.9	75.9 \pm 9.0	4.7 \pm 0.3	4.9 \pm 0.1	6.6 \pm 0.2
32°/22°C	40.7 \pm 4.3	4.9 \pm 0.9	7.9 \pm 1.6	53.5 \pm 6.3	5.0 \pm 0.3	6.0 \pm 0.5	8.1 \pm 0.7
32°/14°C	10.5 \pm 3.8	0.9 \pm 0.4	2.2 \pm 1.1	13.6 \pm 5.3	3.0 \pm 0.3	7.1 \pm 0.3	9.5 \pm 0.5
22°/14°C	3.0 \pm 1.1	0.2 \pm 0.1	3.7 \pm 0.9	6.9 \pm 2.0	2.2 \pm 0.2	6.7 \pm 0.5	7.9 \pm 0.3

Table 11. Effect of cool nights on leaf water potential (Ψ_L) and net CO₂ assimilation rate (A) of rambutan seedlings (Exp.1). Plants grown continuously at 32°/28° or 32°/14°C, or for 20 days at 32°/14°C and then transferred to 32°/28°C after measurements taken at 1000 h on day 0. Data are the means of three (Ψ_L) or four plants (A) per treatment with maximum standard error. Photon irradiance also shown

Treatment	Day -1	Day 0	Day 1	Day 2	Day 3
<i>Leaf water potential (MPa)</i>					
32°/28°C	-1.5	-1.4	-1.4	-1.4	-1.5
32°/14°C	-1.2	-1.0	-1.0	-1.1	-1.3
32°/14°C 20 days	-1.0	-0.9	-0.9	-1.2	-1.2
		Max. SE = 0.1			
<i>Net CO₂ assimilation rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)</i>					
32°/28°C	4.4	7.3	7.3	11.3	10.6
32°/14°C	2.2	2.2	3.9	2.8	3.0
32°/14°C 20 days	-0.8	-0.6	3.8	4.8	4.8
		Max. SE = 1.0			
<i>Photon irradiance ($\mu\text{mol quanta m}^{-2} \text{s}^{-1}$)</i>					
	656	652	783	774	724



Plate 4. Rambutan seedlings following 12 weeks exposure to a range of day/night temperatures. From left to right 32°/28°C, 32°/22°C, 32°/14°C, and 22°/14°C.

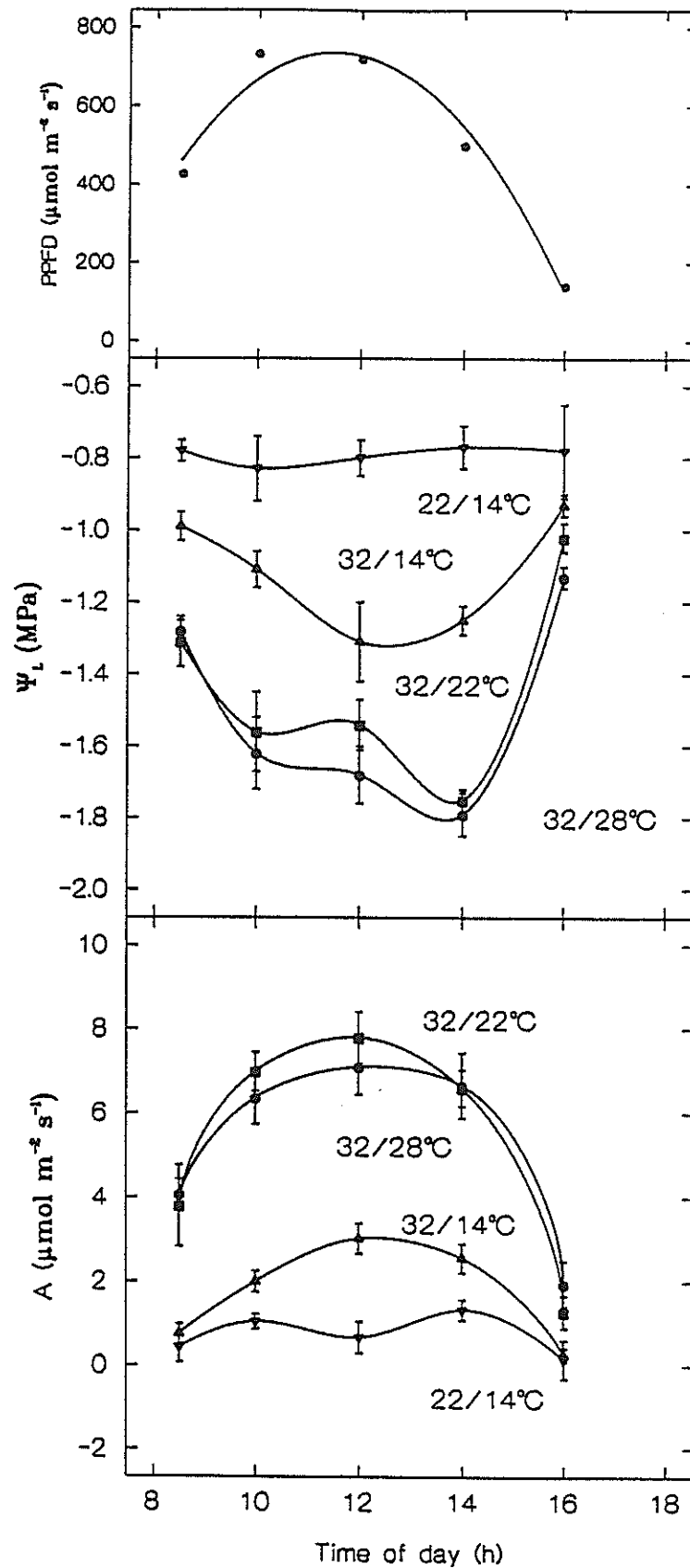


Figure 23. Effect of day and night temperature on leaf water potential (Ψ_L) and net CO_2 assimilation rate (A) of rambutan seedlings (Exp. 1). Data are the means of six (Ψ_L) or eight (A) trees per treatment pooled from two occasions (weeks 15 and 18). Vertical bars indicate \pm standard errors. Photon irradiance (PPFD) also shown.

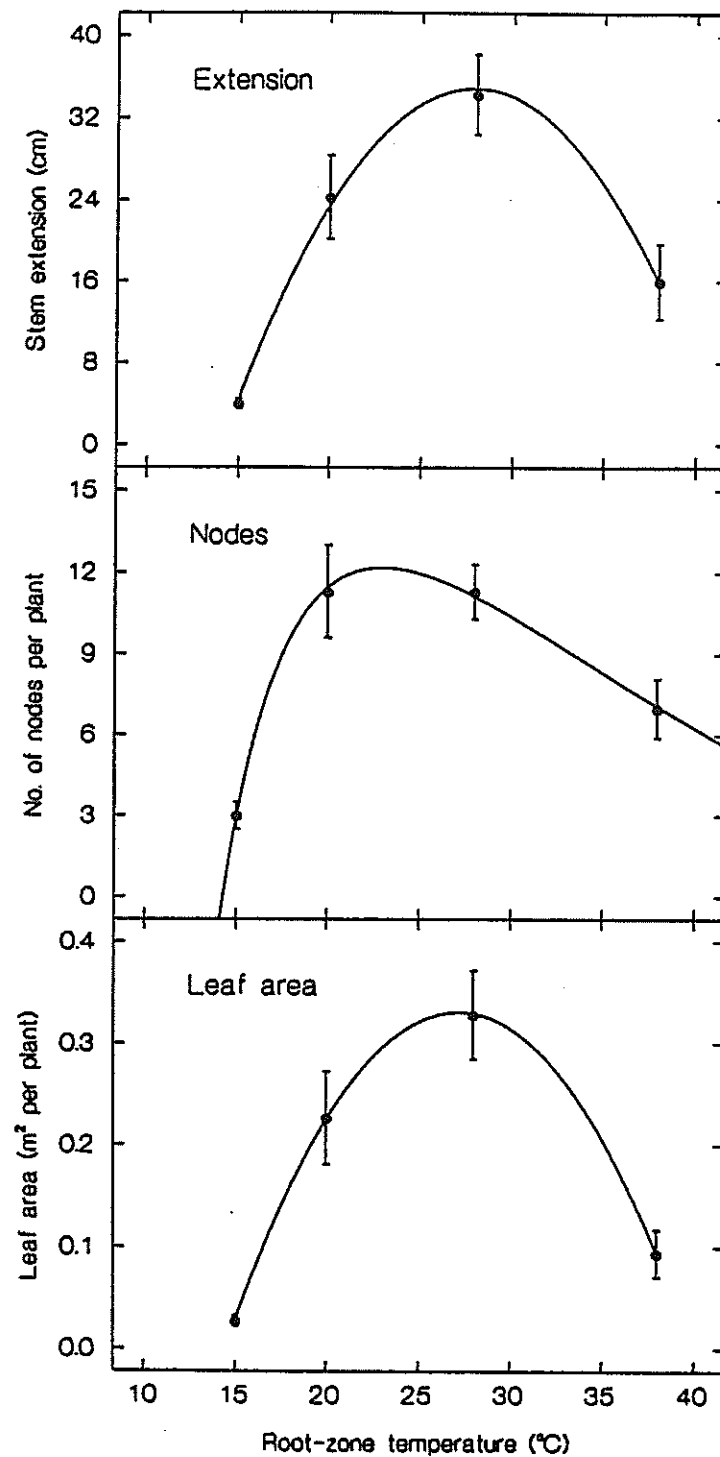


Figure 24. Effect of root zone temperature (T) on the increase in stem extension (ext.), node production (nodes) and leaf area (area) of rambutan seedlings after 12 weeks (Exp. 2). Data are the means of six or seven plants per treatment. Vertical bars indicate \pm standard errors. Regressions are ($r^2 > 99\%$, $P < 0.005$):

$$\begin{aligned} \text{Ext.} &= -108.246 + 10.278 T - 0.185 T^2 \\ \text{Nodes} &= -20.421 + 1497.492/T - 17200.063/T^2 \\ \text{Area} &= -1.211 + 0.115 T - 0.0021 T^2 \end{aligned}$$

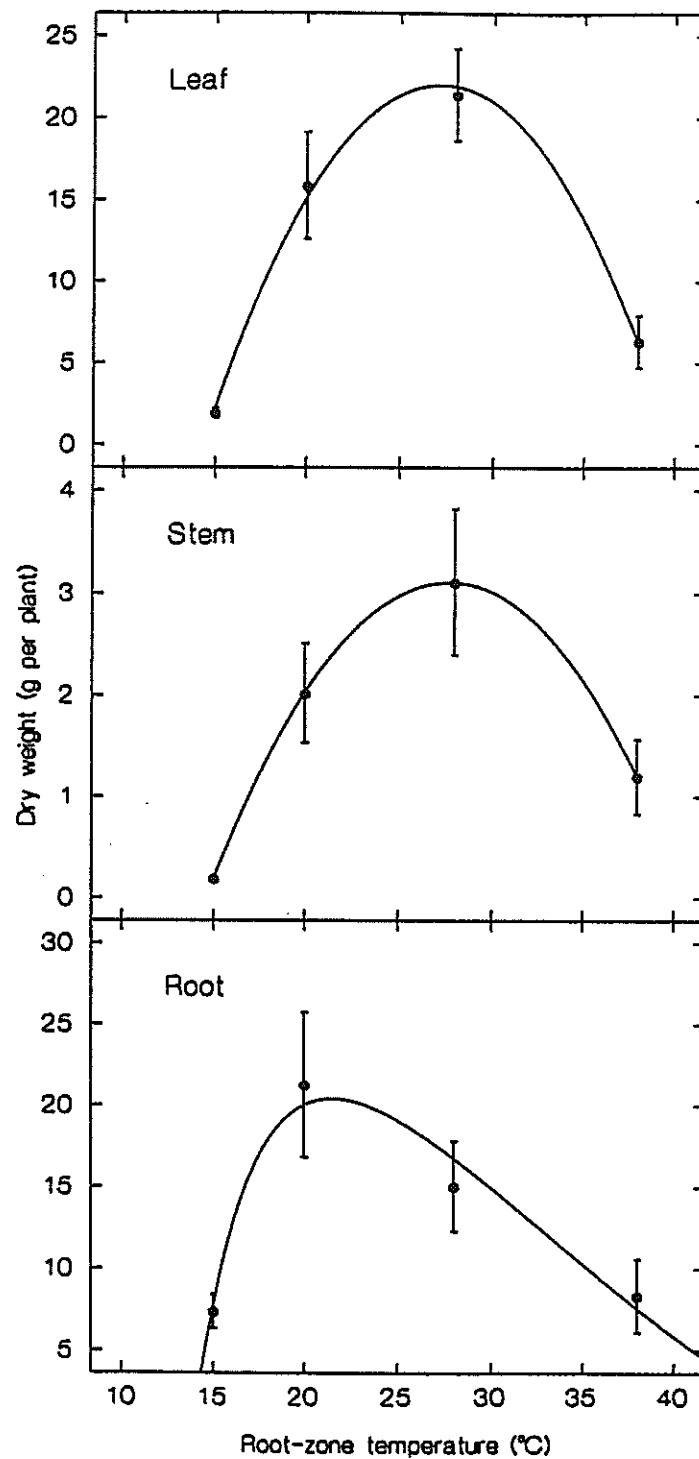


Figure 25. Effect of root zone temperature (T) on the increment in leaf and stem dry weight, and final root dry weight of rambutan seedlings after 12 weeks (Exp. 2). Data are the means of six or seven plants per treatment. Vertical bars indicate \pm standard errors. Regressions are ($r^2 > 96\%$, $P < 0.05$):

$$\begin{aligned} \text{Leaf} &= -76.689 + 7.272 T - 0.134 T^2 \\ \text{Stem} &= -10.755 + 1.000 T - 0.018 T^2 \\ \text{Root} &= -47.478 + 2916.838/T - 31333.868/T^2 \end{aligned}$$

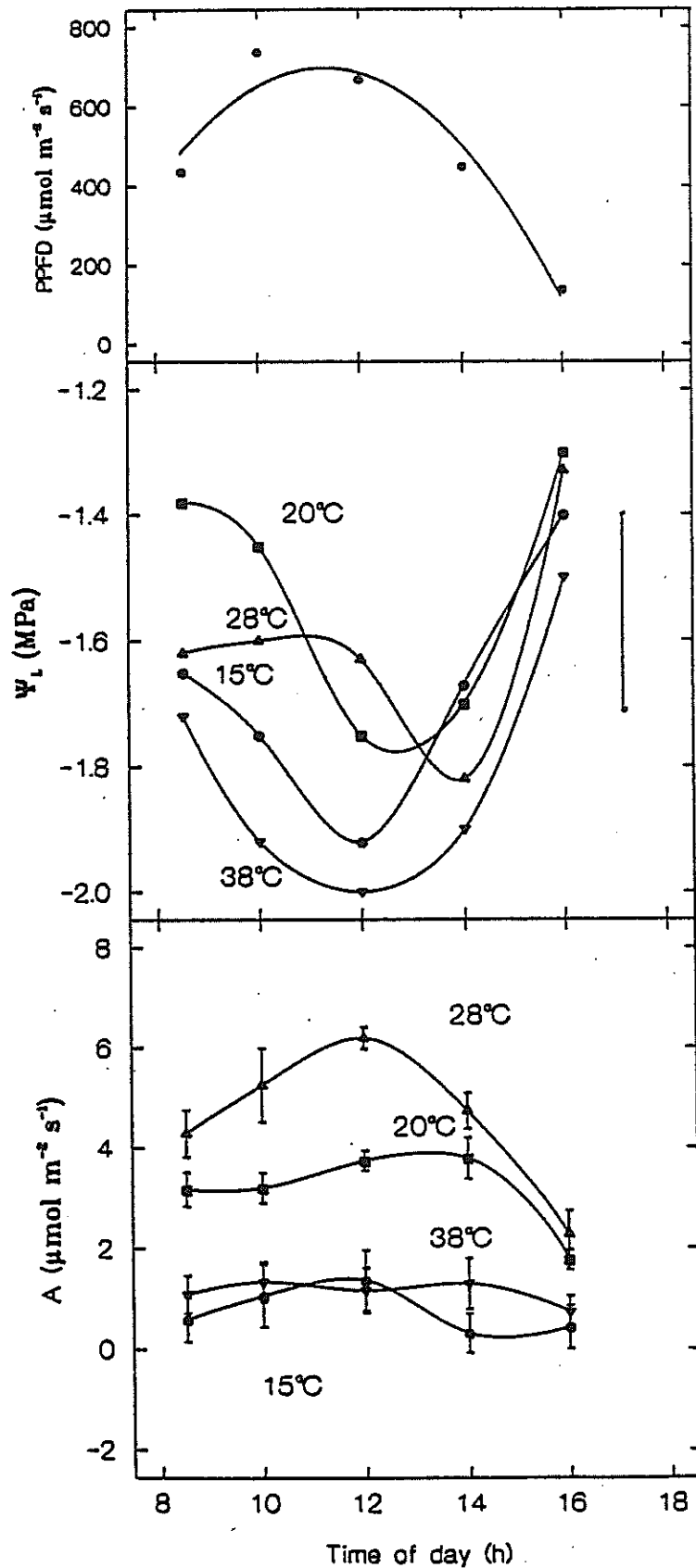


Figure 26. Effect of root zone temperature on leaf water potential (Ψ_L) and net CO₂ assimilation rate (A) of rambutan seedlings (Exp. 2). Data are the means of six (Ψ_L) or eight (A) trees per treatment pooled from two occasions. Vertical bars indicate \pm standard errors (A) or \pm maximum standard error (Ψ_L). Photon irradiance (PPFD) also shown.

7.4 Discussion

Rambutan is native to the lowland wet tropics where nights generally range from 21^o to 24^oC (Nieuwolt, 1982). Similarly, the temperature of the major root zone would vary from 20^o to 30^oC. Our data show that night and root temperatures below 22^oC reduced growth, CO₂ assimilation and dry matter accumulation, whereas there were relatively small changes in water, nutrient and carbohydrate status.

7.4.1 Growth and dry matter production

A 6^oC decline in night temperature from 28^o to 22^oC, coupled with warm days of 32^oC had a minimal impact on flushing, whereas the number of flushes was reduced and the duration of flushing increased substantially as night temperature declined from 22^o to 14^oC (Table 9). Despite the similarity in number of flushes at 28^o and 22^oC, there was a significant reduction in stem extension and total leaf area at the lower temperature. As night temperature decreased further to 14^oC, total leaf area and dry matter accumulation and stem extension declined indicating the sensitivity of rambutan to cool nights. This is in contrast to the results for cocoa (*Theobroma cacao*) recorded by Sale (1969) who found that night temperatures of 23^o, 27^o and 30^oC had very little effect on extension growth compared with the effect of similar day temperatures. There was virtually no shoot growth over the 18 weeks when the rambutans were grown at 22^o/14^oC, whereas growth increased by a factor of five as nights increased from 14^oC to 28^oC with days at 32^oC. In other experiments in cacao, plant growth doubled over the range in day temperatures from 19^o to 31^o when nights were 18^oC (Sena Gomez and Kozlowski, 1987). It can be concluded that rambutan growth is more sensitive to temperature than some other tropical species.

Extension growth, leaf expansion and dry weight accumulation were all highly sensitive to root temperature when shoot temperatures were standardised (Figures 24 and 25). Optimum stem extension, leaf expansion, and leaf and stem dry weight accumulation occurred between 25^o and 30^oC, whereas best node production and root dry weight occurred at lower temperatures of 20^oC to 24^oC. The similarity for temperature optima for stem extension, leaf expansion and leaf and stem dry matter accumulation may be a function of their dependency on the supply of photoassimilates, while the initiation of nodes is more dependent on cell division. Menzel *et al.* (1994) examined the responses of passionfruit plants to root temperature in a glasshouse with an average air temperature of about 24^oC, and showed that shoot and roots responded differently. The two critical root zone temperatures at 90% of maximum leaf and stem growth were about 18^o to 34^oC, while maximum root growth occurred at 38^oC, the highest temperature used. In our experiments, the leaf growth was twice as sensitive to root temperature than to night temperature (x 10 fold compared with a x 5 fold increase in dry weight). Cooling the roots had a greater effect on growth than cooling the shoots.

Temperature also affected dry matter distribution, with the plants at 22^o and 28^oC nights, and at 28^o and 38^oC root zone temperatures, allocating a greater proportion of dry matter to the shoots and less to the roots than at the other regimes. Overall, the shoots were the major sink for dry matter accumulation, with the leaves>stem>roots. In other words, photoassimilates were preferably used in shoot growth, with the roots receiving the excess.

7.4.2 Water relations

The water status of the shoots depends on a balance between uptake by the roots and transpiration by the leaves. Leaf water potential (Ψ_L) depends on the effect of shoot and root temperature on stomatal conductance (g_s) and hence transpiration during the day and on the effects of root temperature on water uptake. In the first experiment, there were mainly differences in night temperature, although there was one treatment with cool days and nights, while in the second experiment roots varied from 15° to 38°C. There was a slight effect of night temperature on Ψ_L , indicating that water uptake did not always keep pace with transpiration during the day (Figure 23). However, when both day and nights were cool, average Ψ_L was up to 0.7 MPa higher, probably due to lower g_s and evaporative demand. These plants had a lower shoot/root ratio (Table 10), which may also have contributed to higher Ψ_L , as suggested for cacao (Sena Gomez and Kozłowski, 1987). These results indicate that low shoot temperatures did not restrict growth by inducing a water deficit in the plants. In the second experiment, average Ψ_L was up to 0.3 MPa lower at 15° and 38°C than at intermediate root temperatures, possibly due to an effect on water uptake at extremes of temperature (Figure 26). In other species, there was a variable response to low root temperatures. For instance in the tropical cacao, Ψ_L was higher in chilled (<10°C) than in non-chilled plants (Joly and Hahn, 1991), while in the temperate *Pinus taeda*, bulk shoot Ψ declined as soil temperature dropped from 24° to 1°C (Day *et al.*, 1991).

7.4.3 Net CO₂ assimilation

Poor growth at low temperatures was associated with lower CO₂ assimilation (A) throughout the day (Figures 23 and 26). In the first experiment, average A was about 50% lower with cool nights, and 80% lower with cool days and nights compared with plants grown at higher temperatures. Surprisingly, A was similar at 32°/22° and 32°/28°C, even though total growth was 30% less. This was presumably related to the former plants having a smaller leaf area. Other tropical fruit trees also appear to be sensitive to low temperatures, although the effects of day and night temperature were not always separated. In mango (*Mangifera indica*), A was substantially lower at 15°/10°C than at 30°/20°C (Pongsomboon, 1991), while in coffee, lowering of the temperature from 24° to 15°C was followed by a slow decrease in A of about 15% after the first day to about 40% after the sixth day (Frischknecht *et al.*, 1982). In other experiments with coffee, chilling on successive nights at about 5°C reduced A progressively on each of the following days and fell to 10% of control values after ten nights (Bauer *et al.*, 1985). The recovery of plants chilled below 10°C for a few days was slow and incomplete, and similarly in our experiments, A recovered to about half of control values after plants were transferred to warm conditions (Table 11). There was no adaptation (for A) for plants given a pretreatment at slightly higher temperatures, whereas the rambutan grown at 22°/14°C for several weeks had A about three times higher than those exposed to these temperatures for only a few days (Table 11).

There was a strong response to root zone temperature, in the rambutans, with A much lower at extremes of temperature, with no diurnal variation, despite significant fluctuations in air temperature, irradiance and Ψ_L in the glasshouse. The response with shoot temperature was not associated with water deficits, however, the plants with roots at 15° and 38°C also had lower Ψ_L . In cacao, chilling of the soil did not inhibit A through an effect on tree water status, which was higher in chilled than in unchilled plants as discussed earlier (Joly and Hahn, 1991). In

other studies in pine seedlings, the initial decrease in A after root chilling appeared to precede any detectable decrease in bulk Ψ_L (Day *et al.*, 1991). These results suggest that low root temperatures do not always reduce A by affecting water relations.

7.4.4 Nutrient and starch concentrations

Plant nutritional status, in particular that of N and P was generally lower at high night temperatures. This can be related to the increase in growth and hence the dilution of the available nutrients in the tissues. However, leaf N and P were also lower at 28° and 38°C root temperatures, indicating an effect of growth dilution at 28°C, and on nutrient uptake at extremes, possibly associated with reduction in water uptake by the roots. There are no nutrient standards available for rambutan, so it was not possible to determine whether the plants were likely to be short of one or more nutrients. However, none of the seedlings showed any symptoms of nutrient shortage or excess. It can be concluded that poor growth at low temperatures was not due to nutrient stress.

The concentrations of starch were low in the leaves, and showed no response to temperature. In contrast, starch was much higher in the rest of the plant and varied with night and root temperature. An accumulation of starch means that photosynthetic activity exceeds extension growth. In tropical species, starch accumulation has been recorded following a cessation of growth due to cold (Chaikiattiyos *et al.*, 1994) and our data confirm higher starch levels in stems of rambutan grown at 14°C. These results and the lower starch concentrations in the stems of the plants grown and at 28° and 38°C root temperatures, mean that the balance between photosynthesis and extension growth was not maintained over the range in environments.

7.5 Conclusion

The reduction in growth and assimilation of rambutan at low temperatures confirms the tropical adaptation of this species (Watson, 1988). However, the results support the view that production is still feasible in areas with cool nights, since a 6°C decline in night temperature from 28° to 22°C, coupled with warm days of 32°C had a minimal impact on flushing. In all areas of northern Australia where rambutans are grown, temperatures below 14°C only occur for a few hours of the night during the winter or dry season, and do not appear to limit production. However, our data suggest that areas where nights remain at or below 14°C for prolonged periods should be avoided. Further experiments are required to determine the impact of short periods of cold on production. Our results also suggest that root temperature is as important as shoot temperature in determining growth.

7.6 Acknowledgments

Greg Haydon and Trevor Rasmussen from the Queensland Department of Primary Industries, Indooroopilly kindly provided the tissue analyses. We also thank Don Simpson at Nambour for collecting some of the leaf water potential data and Derek Eamus, NTU, for providing valuable comments.

7.7 References

- Almeyda, N., Malo, S. E. and Martin, F. W. (1979). Cultivation of neglected tropical fruits with promise. Part 6. The Rambutan. *Science and Education Administration, US Department of Agriculture*.
- Bauer, H., Wierer, R., Hatheway, W. H. and Larcher, W. (1985). Photosynthesis of *Coffea arabica* after chilling. *Physiologia Plantarum*, 64, 449-54.
- Chaikiattiyos, S., Menzel, C. M. and Rasmussen, T. S. (1994). Floral induction in tropical fruit trees: effects of temperature and water supply. *Journal of Horticultural Science*, 69, 397-415.
- Day, T. A., Heckathorn, S. A. and DeLucia, E. H. (1991). Limitations of photosynthesis in *Pinus taeda* L. (loblolly pine) at low soil temperatures. *Plant Physiology*, 96, 1246-54.
- Frischknecht, P. M., Eller, B. M. and Baumann, T. W. (1982). Purine alkaloid formation and CO₂ gas exchange in dependence of development and environmental factors in leaves of *Coffea arabica*. *Planta*, 156, 295-301.
- Joly, R. J. and Hahn, D. T. (1991). Net CO₂ assimilation of cacao seedlings following dark chilling. *Tree Physiology*, 9, 415-24.
- Lam, P. F. and Kosiyachinda, S. (1987). *Rambutan Fruit Development, Postharvest Physiology and Marketing in ASEAN*. ASEAN - COFAF, Jakarta, Indonesia, 82 pp.
- Menzel, C. M. and Simpson, D. R. (1994). Lychee In *Handbook of Environmental Physiology of Fruit Crops Vol. II Subtropical and Tropical Crops* (Eds. B. Schaffer and P. C. Anderson). CRC Press Incorporated, Boca Raton, Florida, USA, pp 123 - 45.
- Menzel, C. M., Haydon, G. F., Doogan, V. J. and Simpson, D. R. (1993). New standard leaf nutrient concentrations for passionfruit based on seasonal phenology and leaf composition. *Journal of Horticultural Science*, 68, 215-29.
- Menzel, C. M., Turner, D. W., Doogan, V. J. and Simpson, D. R. (1994). Root-shoot interactions in passionfruit (*Passiflora* sp.) under the influence of changing root volumes and soil temperatures. *Journal of Horticultural Science*, 69, 553-64.
- Nieuwolt, S. (1982). Climate and agricultural planning in Peninsular Malaysia. *Report of the Malaysian Agricultural Research and Development Institute*. No. ASAS-01-83.
- Pongsomboon, W., Whiley, A.W., Stephenson, R. A. and Subhadrabandhu, S. (1992). Effect of air temperature on diurnal variation of water potential, conductance and CO₂ assimilation of mango (*Mangifera indica* L.). *Acta Horticulturae*, 321, 472-81.
- Rasmussen, T. S. and Henry, R. J. (1990). Starch determination in horticultural plant material by enzymic - colorimetric procedure. *Journal of the Science of Food and Agriculture*, 52, 159-70.

- Sale, P. J. M. (1969). Extension growth of cacao under controlled temperature conditions. *Journal of Horticultural Science*, 44, 189-93.
- Sena Gomes, A. R. and Kozlowski, T. T. (1987). Effect of temperature on growth and water relations of cacao (*Theobroma cacao* var. Comum) seedlings. *Plant and Soil*, 103, 3-11.
- Valmayor, R. V., Mendoza, D. B. Jr., Aycardo, H. B. and Palencia, C. O. (1970). Growth and flowering habits, floral biology and yield of rambutan (*Nephelium lappaceum* Linn.). *Philippine Agriculturist*, 54, 359-74.
- Verheij, E. W. M. and Coronel, R. E. (1991). *Plant Resources of South-East Asia, No. 2 Edible Fruits and Nuts*. Pudoc, Wageningen, The Netherlands.
- Yaacob, O. and Subhadrabandhu, S. (1995). *The Production of Economic Fruits in South-East Asia*. Oxford University Press, Singapore.
- Watson, B. J. (1988). Rambutan cultivars in north Queensland. *Queensland Agricultural Journal*, 114, 37-42.

8.0 The interaction of water potential and Vapour Pressure Deficit as determinants of photosynthesis in rambutan.

D. Eamus and Y. Diczbalis

8.1 Introduction

The wet-dry tropics of Australia are characterised by predictable annual drought of typically 6 to 8 months when no rainfall occurs and leaf-to-air vapour pressure deficit (VPD) is consistently high, typically 3 - 5 kPa (Duff *et al.* 1997). Although irrigation can replace the lack of rain, the large and long-term presence of very high evapotranspirational demand that occurs because of high levels of leaf to air vapour pressure deficit (LAVPD), temperature and solar radiation, can not be easily overcome. Therefore in any assessment of the viability of a horticultural species introduced into this environment must assess plant responses to LAVPD.

Assimilation, ie the fixation of carbon by leaves, underpins growth. Continuous assimilation requires open stomata to allow CO₂ influx, but stomata are generally very sensitive to LAVPD. Therefore if stomata of an introduced species are too sensitive to LAVPD, stomatal limitation on assimilation and therefore growth may occur.

Soil moisture deficits have a significant impact on assimilation rate. In addition it has been shown in some species that stomatal sensitivity to VPD is influenced by leaf water status. Plant water status can be manipulated by irrigation for the purposes of deficit irrigation management practices or to initiate flowering . Furthermore it is important to understand the interaction between water status and assimilation in species that are irrigated so that irrigation can be scheduled effectively, timely and efficiently.

This paper assesses the impact of increasing LAVPD on the assimilation of rambutan, a species which is native to the humid wet tropics of SE Asia where LAVPD is low through out the year.

8.2 Materials and Methods

8.2.1 Plant material and maintenance

Twenty eight month old seedling of the cultivar Jitlee were potted up into 20 L containers four months prior to the experiment and grown in a shade hose under 70 % light at Coastal Plains Research Station. Plants were irrigated daily and liquid fertiliser applied fortnightly. Weeding and application of pesticides were as required. Four weeks prior to the trial the plants were relocated to a shade house (80 % light) adjacent to the Biological Sciences laboratory at the Northern Territory University. Plants were irrigated twice daily, morning and late afternoon prior to the commencement of the trial.

8.2.2 Drought treatments and leaf water potential determinations

Following the four week settling in period, a collection of 12 plants was randomly divided into two sets of six. One group of six (the controls) received irrigation twice daily to field capacity. The other group had their pots sealed into plastic bags and irrigation ceased for approximately 8 days. At approximately 2 day intervals leaf water potential (Ψ_L) was determined using a

Scholander type pressure bomb at 0900 h on one leaf from each tree. Leaf assimilation rate was also determined on that day as described below.

8.2.3 Laboratory studies of assimilation

Assimilation (A) responses to LAVPD, were investigated in the laboratory using a laboratory gas exchange system as described in Wiebel *et al.* (1994). To summarise, the gas analysis system comprises an ADC 225 IRGA in differential mode, a Bingham BI-5ED cooled mirror dew-point hygrometer, Tylan mass flow meters and metal halide 400 W lamps. Four leaf cuvettes, constructed of aluminium with glass tops and hollow floors for temperature regulation were employed. Leaf temperature was measured by addressed thermocouples. Light flux density was measured inside each chamber with a BPX 21 photodiode calibrated with a Li-Cor quantum sensor. Heat reflective glass was placed between lamps and chambers.

The response of assimilation of one leaf from each of four replicate trees per chamber to LAVPD was determined at 30°C and light saturation (1200 mmol m⁻² s⁻¹). The LAVPD was increased from 1.8 to 4.2 kPa incrementally and assimilation determined after equilibration (typically 30 minutes).

8.3 Results

For control plants measured prior to the onset of drought, assimilation increased significantly as LAVPD increased from approximately 2 to approximately 4.2 kPa. Assimilation peaked at this value of LAVPD and then declined significantly as LAVPD increased further to 5 kPa (Figure 27). Leaf water potential at this time averaged approximately -0.22 MPa (Table 12).

Forty four hours into the drought period Ψ_L had declined to approximately -0.51 MPa (Table 12) and the peak value of assimilation had declined by approximately 25%. However, as was observed in control trees, assimilation rate increased as LAVPD increased from approximately 2.8 kPa to approximately 5.0 kPa (Figure 27).

As the drought progressed through 96 hours and through to 8.75 days, assimilation continued to decline substantially and the slope of the response of A to LAVPD declined substantially. After 8.75 days, assimilation averaged approximately 0.6 $\mu\text{mol m}^{-2} \text{s}^{-1}$ over the entire range of LAVPD imposed and Ψ_L was at its maximum of -2.5 MPa. Four days after watering the droughted plants assimilation had essentially recovered to pre-drought levels and the large increase in assimilation as LAVPD increased was once more apparent (Figure 27).

Table 12. Leaf water potential (Ψ_L) of control and droughted rambutan leaves. Data are means of four readings.

Time (hours/days of drought)	Control plants Ψ_L (MPa)	Droughted plants Ψ_L (MPa)
0	-0.25	
44 hours	-0.22	-0.51
92 hours	-0.20	-0.63
8.75 days	-0.17	-2.5
4 days after re-watering	-0.2	-0.22

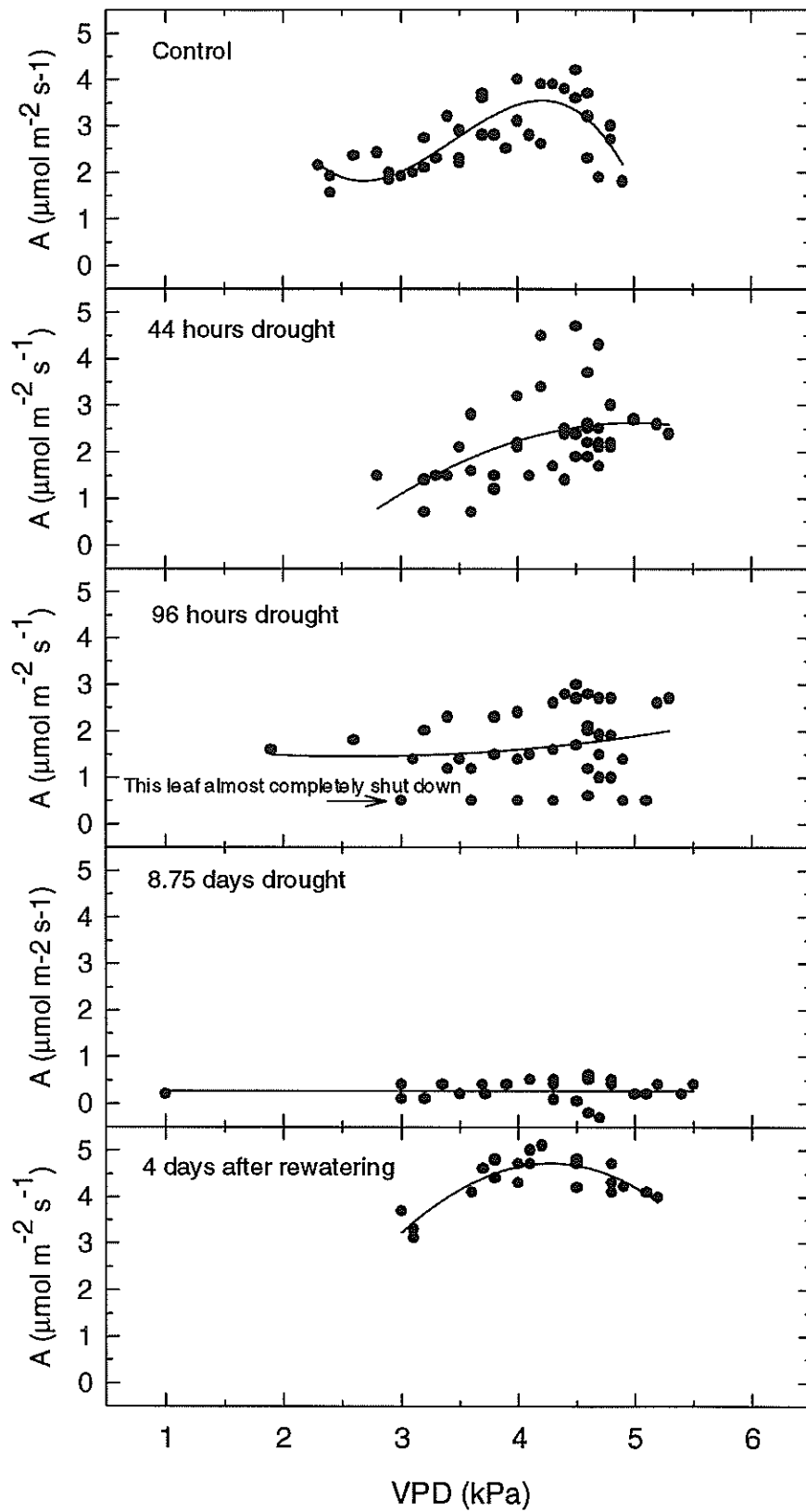


Figure 27. Net CO₂ assimilation of rambutan leaves of control, droughted (44 hours to 8.75 days) and drought recovery treatments exposed to a range of VPD.

8.4 Discussion

There are four significant findings from this experiment. The first is that as drought progressed, maximum assimilation rate declined curvilinearly. Such a result is generally observed in all experiments where drought is imposed relatively gradually and assimilation measured. The principal initial cause of the decline in assimilation is due to the progressive decline of stomatal conductance. As leaf water status declines, stomatal conductance declines in an effort to restrict water loss and to increase water-use-efficiency. However as drought develops beyond a critical value, the assimilation process *per se* is affected and chloroplast function is lost.

The second significant finding was that recovery from drought was rapid and complete, but only in leaves that remained on the plant. Leaf loss was extensive and very sudden in rambutan once a critical water potential (not determined) was reached. This is liable to be related to the occurrence of xylem emboli which generally increase with increasing drought and which can cause leaf drop. Clearly, leaves that had been dropped were not assessed for assimilation rate. However, those leaves that remained showed complete and rapid recovery of water potential and assimilation rate.

The third significant finding was that assimilation rate did not decline immediately upon the increase in LAVPD from the lowest imposed value (typically 1.5-2.5 kPa). Rather, assimilation increased in control trees and in trees that had been droughted but rewatered for four days, as LAVPD increased from approximately 2.0 to approximately 4.0 kPa. Thus a peak in assimilation rate occurred at an intermediate LAVPD and not at the smallest LAVPD. This response was absent, however, in trees that had begun to experience drought for only a short (44 hours; 92 hours) period.

The large majority of published papers on the response of A to increasing LAVPD show a decline in assimilation rate with increasing LAVPD from the lowest values of LAVPD imposed. For example, Weibel (1993) showed that in mangosteen, a plant which originated in the same environment as rambutan, A declined rapidly with increasing VPD above 1.0 kPa. However, notable exceptions are found, including coniferous species, (Grieu *et al.* 1988); *Oryza sativa* (Kawamitsu *et al.* 1993); *Tradescantia virginiana* (Nonami *et al.* 1990) and *Helianthus* spp (Turner *et al.* 1984). In most of these examples, assimilation was unresponsive (zero slope) to increasing VPD until a critical VPD was attained, above which assimilation declined. Both stomatal and direct mesophyll effects of too high a transpiration rate (resulting from a large LAVPD) and declining leaf water potential have been proposed to explain the decline in A as LAVPD increase past a threshold value. However, the cause of a peak in assimilation rate at intermediate values of LAVPD is highly unusual and worthy of further study as to the underlying mechanism. Only one other paper reports such a result (Nonami *et al.* 1990). Most importantly, this increase in A with increasing LAVPD was observed only when leaves were not water stressed (water potential greater than -0.15 MPa). Remarkably, when water potential declined to just -0.25 MPa, this pattern was lost and assimilation declined with increasing LAVPD. This is exactly what was found in the present study. We believe that the mechanism underlying this lies in the ratio of the amount of water supplied to the stomatal guard cell compared to the amount of water supplied to the subsidiary cell. As LAVPD increases from 2.0 kPa to 4 kPa in well watered plants, the ratio of the supply of water to the guard cell compared to the supply to the subsidiary cell increased and hence stomatal aperture increased and hence assimilation rate increased. As LAVPD increased further, this ratio declined and stomatal aperture declined and assimilation declined. The cause of the decline in the ratio is the fact that

as LAVPD increased, cuticular water loss becomes more significant and hence water supply to subsidiary cells declined more than the decline in water supply to the guard cells.

The fourth significant result was that as drought developed, sensitivity to increasing LAVPD declined. Such a loss of stomatal sensitivity to LAVPD as plant water status declined has been observed previously (Johnson and Ferrell 1983; Schulze and Kopper 1979). It has been proposed that this results from a change in the 'relative advantage' exerted by subsidiary cells *versus* guard cells (Johnson and Ferrell, 1983). It is also possible that as leaf water potential declines, the rate of supply of ABA in the transpiration stream may increase and this dampens any LAVPD response of the stomata and hence assimilation. A direct effect of transpiration rate on assimilation is also possible.

8.5 Conclusions

This preliminary experiment showed that rambutan is (a) poorly suited to survival without irrigation in the wet-dry tropics of Australia because it has stomata that are relatively insensitive to LAVPD and appears poorly able to regulate water loss; and (b) that rambutan is clearly worthy of greater study since the assimilation versus LAVPD relationship is extremely unusual. Such further study may contribute to our understanding of the mechanisms underlying stomatal and assimilation responses to LAVPD, a topic that is receiving considerable attention at present.

8.6 References

- Duff, G. A., Myers, B.A., Williams, R.J., Eamus, D., O'Grady, A and Fordyce, I., (1997). Seasonal patterns of soil moisture, vapour pressure deficit, tree canopy cover and predawn water potential in a northern Australian savanna. *Australian Journal of Botany*, 45: 25-32.
- Grieu, P., Guehl, J.M and Aussenac, G. (1988). The effects of soil and atmospheric drought on photosynthesis and stomatal control of gas exchange in three coniferous species. *Physiologia Plantarum*, 73: 97-104.
- Johnson, J.D. and Ferrell, W K (1983). Stomatal response to vapour pressure deficit and the effect of water stress. *Pl. Cell and Environ.*, 6: 451-456.
- Kawamitsu, Y., Yoda, S., and Agata, W. (1993). Humidity pretreatment affects the responses of stomata and CO₂ assimilation to vapour pressure difference in C₃ and C₄ plants. *Plant, Cell and Environ.* 34: 113-119.
- Nonami, H., Schulze, E-D and Ziegler, H. (1990). Mechanisms for stomatal movement in response to air humidity, irradiance and xylem water potential. *Planta*, 183: 57-64.
- Schulze, E-D and Koppers, M (1979). Short-term and long-term effects of plant water deficits on stomatal responses to humidity in *Corylus avellana*. *Planta*, 146: 319-326.
- Turner, NC, Schulze, E-D and Gollan, T. (1984). The response of stomata and leaf gas exchange to vapour pressure deficits and soil water content. *Oecologia* 63: 338-342.

Weibel, J. (1993). Physiology and growth of mangosteen (*Garcinia mangostana* L.) seedlings. PhD Thesis, Technische Universität Berlin.

Wiebel, J., Eamus, D, Chacko, E K and Downton, W J S. and Ludders, P (1993). Gas exchange characteristics of mangosteen leaves. *Tree Physiology* 13: 55-69.

9.0 Effect of pre-flowering irrigation on flowering and yield of rambutan.

Y. Diczbalis and P. Watson

9.1 Introduction

Flowering in rambutan is induced by either a period of drought (Whitehead, 1959 as cited by Tindall 1994, Tatt, 1976) or low temperature (Manakasem 1995). The phenology of the rambutan grown in the NT (12 - 14 °S) suggests that low night temperatures in June and July cause a cessation in vegetative growth and initiate flowering in July to September (Diczbalis *et al.* chapter 3). This results in fruit being ready for harvest from November to December, which is often a low price period, due to competition with other fruits available on the market. Market information suggests that September/October and late January are more favourable harvest periods for rambutan in terms of price (Ngo 1996).

The pattern of flowering of rambutan, in its native environment may offer a key to whether water deficit can be used to promote early flowering. The fruiting season for rambutan varies throughout peninsula Malaysia and Sarawak (FAMA 1988) and local experience suggests that dry periods promote flowering. Hence, in Malaysia, regions with three to four week dry periods are preferred for commercialisation of rambutan (MARDI 1982).

This work was initiated to test the hypothesis that a period of soil moisture stress imposed prior of seasonally induced flowering would induce earlier flowering and hence harvest.

9.2 Materials and Methods

We examined the effects of pre-flowering irrigation treatments on time and synchrony of flowering. Four treatments were imposed; for an eight week period, from the end of the wet season in late April 1993 to the commencement of flowering in early July. Treatments were imposed on eight four year old replicate trees of the variety R167. The irrigation treatments were 10.5 mm/day (high); 5.1 mm/day (medium); 3.2 mm/day (low) and 10.8 mm every second day (medium 2nd daily). At the commencement of flowering (early July) all trees received approximately 16.0 mm/day in two irrigations per day, through to harvest. Trees were harvested as the fruit ripened and yields recorded. Yield data, weekly and total, are the means of eight trees and are presented with standard errors (SE).

Soil tensions (Ψ_s) were monitored on two replicate trees per treatment at three depths (20, 40 and 80 cm). The data is presented as means without error bars. Phenology (1st flower, peak flower, early fruit set, peak set and peak harvest) was recorded weekly and data are the subjective means of eight trees and hence are not presented with any measure of variation.

9.3 Results

9.3.1 Soil Moisture Monitoring

Soil tensions at 20, 40 and 80 cm were monitored from the initiation of treatments in late April until final harvest in late December (Figure 28). The irrigation treatments were only imposed for the period late April until early July with all treatments receiving the same level of irrigation from mid July until harvest.

During the pre-flowering period (late April to early July) there were distinct differences in the soil tensions, or level of dryness obtained, between the different treatments. Under high (10.5 mm/day) irrigation inputs, tensions at all depths remained above -0.04 MPa. Under the medium (5.1 mm/day) treatment tensions at 20 cm fell below -0.05 MPa and tensions at 80 cm reached -0.04 MPa whereas tensions at 40 cm remained above -0.03 MPa. In the low (3.2 mm/day) and medium 2(10.8 mm every second day) treatments tensions at all depths fell below 0.04 MPa with tensions at 20 and 40 cm reaching -0.08 MPa in the low irrigation treatment. Simply stated, the less water added the drier the soil became, however, there were differences in the moisture distribution between the two medium irrigation treatments with daily irrigation resulting in improved soil moisture at 40 and 80 cm depths. At no time during the soil moisture induced stress period was there any visual indication of tree water stress.

Following the onset of flowering all treatments received 16 mm/day in two irrigations (0800-0930 hr and 1300-1430 hr). Soil tension, particularly at 80 cm differed slightly between treatments, however, at 20 and 40 cm tensions were low which indicated that sufficient irrigation inputs occurred.

9.3.2 Temperature

Daily maximum and minimum temperatures were monitored from the 2 May until late July. The weekly means were calculated and are presented in Table 13. The mean weekly maximum temperature fluctuated little and ranged from 31.9° to 34.3°C. The mean weekly minimum was approximately 20°C until early June and declined from the 6 June and remained below 19.0°C up until the end of the recording period. During the period 27 June to 18 July the weekly mean minimum ranged from 14.6° to 17.1°C. This period is characterised by stable maximum and declining minimum temperatures.

Table 13. Weekly mean minimum temperatures from early May until early August 1993.

Week ending	9/5	16/5	23/5	30/5	6/6	13/6	20/6	27/6	4/7	11/7	18/7	25/7	1/8
Max. Temp. °C	33.6	33.7	33.3	32.4	33.7	32.3	32.9	33.1	33.8	32.0	31.9	33.1	34.3
Min Temp. °C	20.1	19.1	19.1	19.7	19.8	17.4	18.6	15.8	17.1	16.9	14.6	17.4	18.6

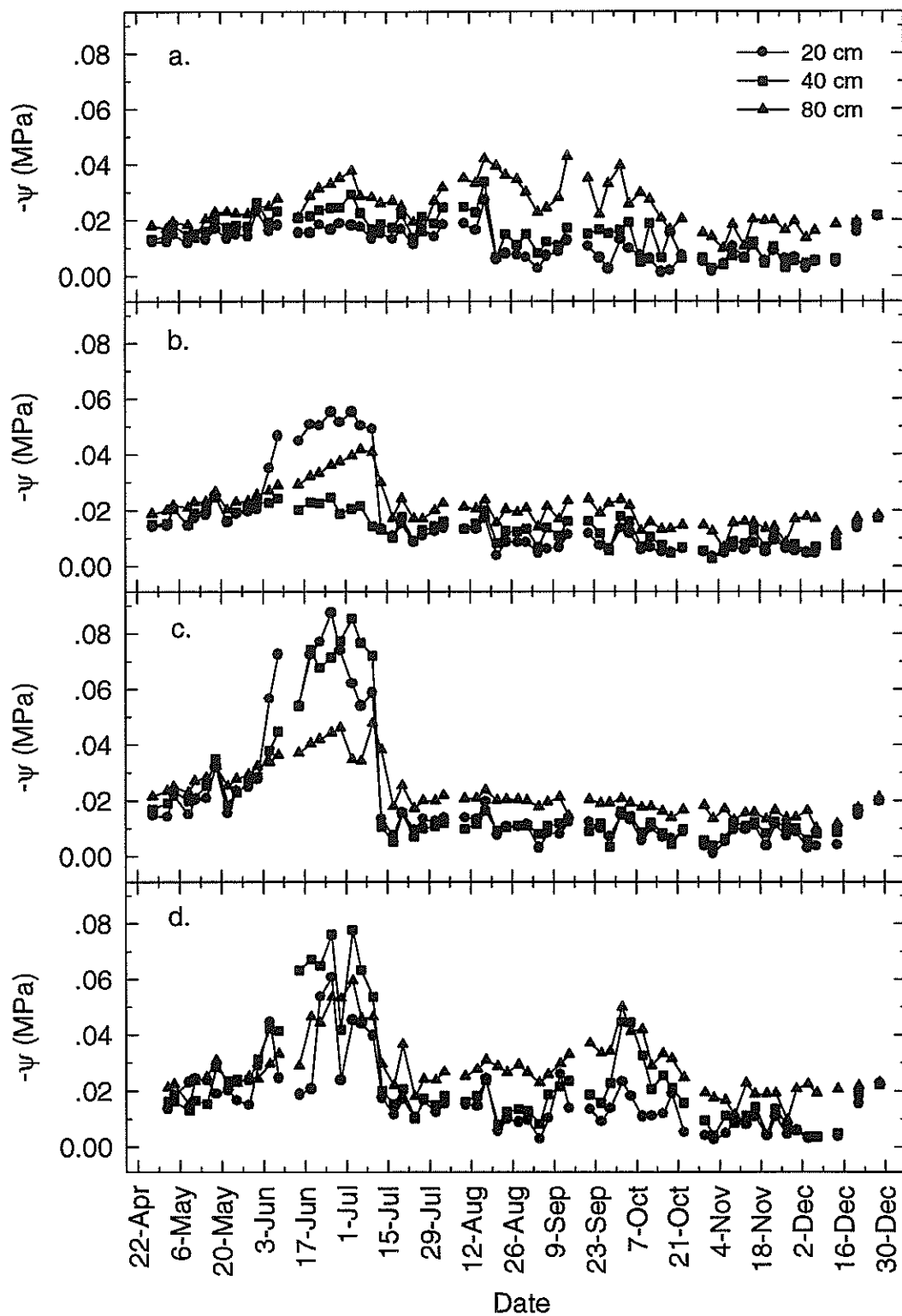


Figure 28. Mean soil tensions ($-\Psi_s$, MPa) at 20, 40 and 80 cm for rambutans irrigated at four levels during the pre-flowering period (from late April to early July). a. High (10.5 mm/day); b. Medium (5.1 mm/day); c. Low (3.2 mm/day) and d. Medium 2nd daily (10.8 mm every second day). From early July all treatments received 16 mm/day in two irrigations until harvest.

9.3.3 Phenology

Trees receiving the least water during the pre-flowering period were observed to have fewer vegetative flushes and reached peak flowering approximately three weeks earlier than trees under the higher irrigation regimes despite 1st flowering being recorded only a week earlier (Table 14).

Table 14. Dates of flowering and harvest for a range of pre-flowering irrigation treatments. Dates are the means of eight trees per treatment.

Irrigation treatments	Growth stages				
	1st flowers	Peak flowering	Early fruit set	Peak set	Peak harvest
High	28 Jun	20 Sep	23 Aug	11 Oct	18 Dec
Medium	21 Jun	23 Sep	16 Aug	27 Sep	10 Dec
Low	14 Jun	30 Aug	9 Aug	20 Sep	23 Nov
Medium (irrigated 2nd daily)	28 Jun	30 Aug	16 Aug	13 Sep	30 Nov

This difference in peak flowering was maintained at the fruit set and peak harvest stage. The period from peak flowering to peak harvest was 12.7, 12.4, 12.1 and 13.1 weeks for the high, medium, low and medium 2nd daily irrigation treatments respectively.

9.3.4 Yield and harvest synchrony

Total yield was not affected by pre-flowering irrigation treatments. An average yield of 30 kg per tree was obtained (Figure 29). Harvest synchrony was improved by the two irrigation treatments which caused the greatest increase in soil tensions pre-flowering, as 84% and 72% of the crop was harvested in the first three weeks in the low and medium second daily treatments respectively, compared to 36% and 58% for the high and medium irrigation treatments (Table 15).

Table 15. Effect of pre-flowering irrigation on weekly yield and harvest synchrony (percentage of total harvested). Yield data presented are the means of eight trees per treatment \pm standard error.

Yield (kg/tree)	Pre-flowering irrigation treatment			
	10.5 mm/day	5.1 mm/day	3.2 mm/day	10.8 mm/2 day
19 Nov.	1.4 \pm 0.7 (4.7)	3.4 \pm 2.0 (11.4)	12.1 \pm 3.1 (38.5)	8.8 \pm 2.6 (29.5)
26 Nov.	3.2 \pm 1.3 (15.6)	0.8 \pm 0.7 (14.0)	6.1 \pm 2.2 (57.8)	0.0 \pm 0.0 (29.5)
3 Dec.	6.0 \pm 2.9 (35.7)	13.5 \pm 2.5 (58.8)	8.2 \pm 2.6 (84.0)	12.6 \pm 4.4 (71.5)
10 Dec.	5.7 \pm 5.3 (54.8)	0.0 \pm 0.0 (58.8)	0.0 \pm 0.0 (84.0)	2.4 \pm 2.3 (79.6)
17 Dec.	0.0 \pm 0.0 (54.8)	9.2 \pm 6.1 (89.5)	3.9 \pm 2.9 (96.5)	5.7 \pm 4.2 (98.5)
26 Dec.	9.2 \pm 2.9 (85.8)	3.2 \pm 1.6 (100)	1.1 \pm 1.0 (100)	0.4 \pm 0.4 (100)
3 Jan	4.2 \pm 2.6 (100)	0.0 \pm 0.0 (100)	0.0 \pm 0.0 (100)	0.0 \pm 0.0 (100)

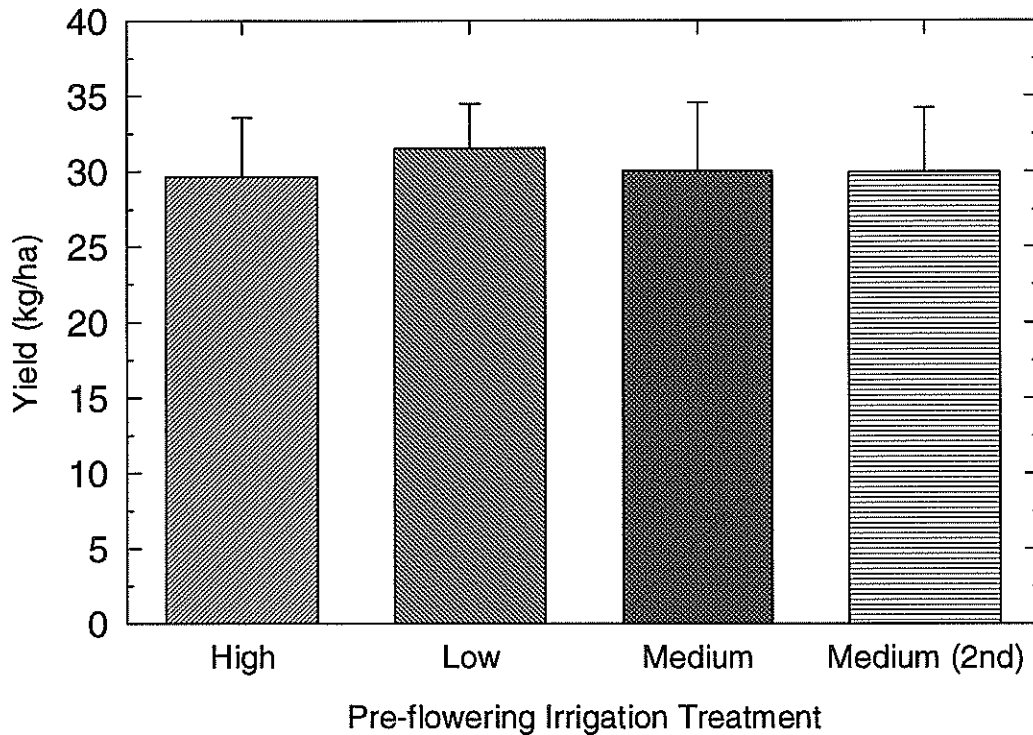


Figure 29. Mean yield (kg/tree) for rambutans irrigated at four levels during the pre-flowering period. a. High (10.5 mm/day); b. Medium (5.1 mm/day); c. Low (3.2 mm/day) and d. Medium 2nd (10.8 mm every second day). Data are the means of eight trees per treatment. Vertical bars indicate \pm standard error.

9.4 Discussion

Pre-flowering drought did induce earlier flowering and improve harvest synchrony relative to trees in which soil moisture was maintained at a high level. The flowering and harvest timing which resulted from the pre-flowering drought treatments however, were not out of season and remained within the normal seasonal patterns experienced in the Top-End of the NT (Diczbalis *et al.* Chapter 3).

The mechanisms which cause flowering in tropical fruit trees have been well discussed by many authors. The environmental factors most implicated in flowering are temperature, soil moisture deficit and irradiance. Chaikiattiyos *et al.* (1994) reported that for avocado (cv.Hass), litchi (cv. Wai Chee) and mango (cv. Sensation) temperatures below 25°C for avocado and 20°C for litchi and mango are essential for flowering and cannot be replaced by water stress, whereas the control of flowering in lemon (cv. Lisbon), in the temperature range 18° to 30°C, was mainly controlled by water stress. Factors often associated with flowering, in tropical species, whether caused by drought or reduced temperature, include an interruption or reduction to vegetative growth and associated carbohydrate accumulation in the shoots (Dick 1995; Menzel *et al.* 1989).

The environmental factors which induce flowering in rambutan are not well understood. However, a period of seasonal drought is reported to be a key factor in the flowering and fruiting patterns of the tree in Malaysia, Philippines and southern Thailand (Whitehead 1959 as cited by Tindall 1994; Tatt 1976, Valmayor *et al.* 1970 and Wanichkul *et al.* 1990). Work carried out in Chantaburi, Thailand suggests that changes in temperature, particularly a reduction in night temperature, promotes flowering (Manakasem 1995).

Although the pre-flowering irrigation treatments did not induce flowering and fruiting earlier than can be expected there was good evidence that the treatments which induced mild drought conditions synchronised flowering and fruiting. Soil moisture deficits have been found to synchronise flowering and hence harvest maturity in other tropical crops. Drinnan and Menzel (1994) report that in coffee a constant period of water stress during the late stages of floral development after floral initiation is complete provides a practical method to achieve synchronised flowering and harvest maturity. Nakajima *et al.* (1993) reported that flowering in pomelo was intensified as the duration of pre-flowering stress increased.

Flowering in rambutan appears to be initiated by drought and low temperatures. The data available from work carried out in this project and from overseas observations suggest that low night temperatures alone are sufficient to induce flowering. There is insufficient evidence to say that drought alone can induce flowering, although there is no doubt it is an important induction agent. Drought conditions in the tropics are inevitably associated with reduced night temperatures, although these temperature changes are small they may be sufficient to induce flowering. Manakasam (1995) reported that night temperatures dropped 2-3°C with the onset of the dry season and multiple linear regression analysis showed that for every degree night temperature decreased, flower induction increased by 6.7%.

The seasonal climate in the Top-End of the NT is well suited to manipulation of soil moisture pre-flowering. The assured rain free period from the end of the wet season (late April - mid May) until flowering (June/July) allows soil moisture to be manipulated *via* irrigation inputs. However, during this time night temperatures are decreasing and will undoubtedly influence flower induction. The phenology monitoring data (Chapter 3) shows that flowering occurs at approximately the same time of year despite the differences in pre-flowering soil moisture which occurred over different seasons and farms. This trial shows that pre-flowering soil moisture deficits can influence flowering date and synchrony. Hence manipulation of irrigation pre-flowering can be used to manipulate crop timing within the constraints of seasonal conditions.

9.5 References

- Chaikiattiyos S., Menzel, C.M. and Rasmussen, T.S. (1994). Floral induction in tropical fruit trees: effects of temperature and water supply. *Journal of Horticultural Science* 69:397-415.
- Dick, J.M. (1995). Flower induction in tropical and subtropical forest trees. *Commonwealth Forestry Review*. 74:115-120.
- Drinnan, J.E. and Menzel, C.M. (1994). Synchronization of anthesis and enhancement of vegetative growth in coffee (*Coffea arabica* L.) following water stress during floral initiation. *Journal of Horticultural Science* 69:841-849.

- FAMA (1988). Exotic fruits of Malaysia. Federal Agricultural Marketing Authority, Kuala Lumpur, Malaysia.
- Manakasem, Y. (1995). Changes in apices and effect of microclimate on floral initiation of rambutan (*Nephelium lappaceum* L.). (In Thai) Suranaree Journal of Science and Technology 2:81-87.
- MARDI (1982). Suitability of regions for fruit cultivation in peninsular Malaysia. Special report No: PTS-01-83. Malaysian Agricultural Research and Development Institute, Serdang.
- Menzel, C.M., Rasmussen, T.S. and Simpson, D.R. (1989). Effects of temperature and leaf water stress on growth and flowering of litchi (*Litchi chinensis* Sonn.). The Journal of Horticultural Science. 64:739-752.
- Nakajima, Y., Susanto, S. and Hasegawa, K. (1993). Influence of water stress in autumn on flower induction and fruiting in young pomelo trees (*Citrus grandis* (L.) Osbeck). Journal of the Japanese Society for horticultural Science 62:15-20.
- Ngo, H. (1996). Economic assessment of rambutan production in the Northern Territory. NT Department of Primary Industry and Fisheries, Technical Bulletin No. 251.
- Tatt, O.H. (1976). Climatic changes in water balance and their effects on tropical flowering. Planter, Kuala Lumpur 52:174-179.
- Tindall, H.D. (1994). Rambutan cultivation. FAO Plant Production and Protection Paper 121. Food and Agriculture Organization of the United Nation.
- Valmayor, R.V., Mendoza, D.B., Aycardo, H.B. and Palencia, C.O. (1970). Growth and flowering habits, floral biology and yield of rambutan (*Nephelium lappaceum* Linn.). Philippine Agriculturist 52:359-374.
- Wanichkul, K., Osotsapa, Y., Subhadrabandha, s., Masuthon, S., Kaewprasit C and Nakorn M. (1990). Effects of climatic factors on total non-structural carbohydrates, total nitrogen in leaves and flower bud initiation of rambutan (*Nephelium lappaceum* L. cv Rong Rian). (In Thai) Kasetsart Journal Natural Sciences 24:8-15.

10.0 Estimates of rambutan water requirements and irrigation recommendations for Northern Territory orchards.

Y. Diczbalis

10.1 Introduction

Water requirements and efficient irrigation management strategies are essential information for the correct management of tree crops. This information is particularly essential when growing plants outside their native environment in a climate which is considered hostile to the species. The rambutan is native to the wet tropics of SE Asia where annual rainfall is high and well distributed. The introduction of the crop to the wet/dry tropics where rainfall exceeds evaporation in only four months of the year necessitates the use of irrigation for the trees survival.

Tree water requirements are generally calculated from information collected on water inputs (rainfall or irrigation), drainage losses and measurements of soil moisture changes. Crop water requirements are generally expressed as a percentage of evaporation from an open pan and hence the term crop factor was devised to express the ratio of tree water use to evaporation (Doorenbos and Pruitt, 1977). The long term monitoring of tree phenology and in relation to environmental variables, including soil volumetric moisture, as reported in Chapter 3, allows water use (evapotranspiration) to be calculated.

The following chapter describes the technique used to calculate rambutan water use and the irrigation recommendations which have evolved and disseminated to rambutan growers in the NT.

10.2 Materials and Methods

Three farms were selected and three trees per site were monitored weekly for three years for soil moisture status and tree phenology as described in Chapter 3. Other recordings included, weekly rainfall, irrigation inputs and maximum and minimum temperatures.

10.2.1 Soil moisture monitoring

Soil moisture monitoring occurred on three sample trees within an irrigation block on each orchard. Soil volumetric moisture monitoring was undertaken with a Cambell 503DR Neutron Moisture Probe (NMP). Access tubes (aluminium) 1.5 m in length were installed to a depth of 1.4 m at a site which was 1.0 m from the sprinkler and 1.5 m from the tree trunk. Nine depths (10, 20, 30, 40, 50, 60, 80, 100 and 120 cm) were monitored at each tube. Data was downloaded onto a spreadsheet and mean volumetric soil moisture was calculated using a calibration equation developed for each site. Tensiometer tubes (20, 40 and 80 cm) were installed opposite to the NMP access tube at each tree site. Tensions were read weekly using a Loktronic metre (Lok, 1988) and then tubes were maintained and refilled as required. Data was collated and means calculated.

10.2.2 Irrigation inputs and rainfall

Irrigation inputs were measured using a Amiad multi-jet water metre installed on a lateral line approximately 10 trees up from the end of the line. The position of the meter was determined by the total flow rate required to meet the minimum flow rate specifications of the metre. Accumulated flow readings (m³) were made weekly and the inputs (L/tree) for the week calculated. Irrigation inputs were also expressed as mm per week by dividing the water inputs (L/tree) by the tree canopy area (m²).

Rainfall inputs were measured and recorded weekly at each site using a Nylex rainfall gauge.

10.2.3 Water use calculation

The soil volumetric moisture, irrigation and rainfall data collected during our monitoring studies (Chapter 3) allow water use and crop factors to be calculated. The water use calculated does not distinguish between actual tree water use, evaporative loss and deep drainage. However, the calculation occur over a period 1 April to 9 December when tensiometer data at 80 cm in most years suggests that there is minimal through drainage (Figures 1-9). Therefore water use would be primarily due to tree water requirements and direct evaporative loss. Water use (total evapotranspiration plus an unknown but small drainage component) and the crop factor was calculated from the weekly changes in mean soil moisture data (mm of moisture/1.2 m of soil profile), records of water inputs (rainfall and irrigation) expressed in mm and average evaporation records for Darwin . Table 16 describes the spreadsheet inputs and the calculations for water use and crop factor which took place.

Table 16. Example of spreadsheet inputs and calculation of water use and crop factor.

Week ending	Mean Vol. soil moisture (mm/1.2 m)	Rain fall (mm)	Irrigation (mm)	Water use	Av. weekly evaporation (mm)	Crop Factor
3 Jun	244.42	0	37.23	28.85	50	0.57
10 Jun	238.91 ^b	0 ^c	36.38 ^d	42.74	50	0.85
17 Jun	234.56 ^c	2	27.31	40.72 ^a	50 ^e	0.81 ^f
24 Jun	234.76	0	30.57	29.11	50	0.58
1 Jul	240.95	0	51.89	24.38	50	0.48

Water use a(40.72) = (b(239.91) + c(0) +d(36.38)) - e(234.56)

Crop factor f(0.81) = a(40.72)/g(50)

Mean crop factors were then calculated for the following periods; preflowering (1 April - 1 July), flowering (8 Jul - 5 August) and fruit development (12 August to 9 December).

10.3 Results

Table 17 summarises the crop factor calculations for the three orchards over three years of data collection. Missing data occurs in two sites over some periods because the tensiometer data (Figures 1-9) suggest that the drainage component was too high and the data did not truly reflect evapotranspiration.

The data collected suggests that the period of lowest water use occurs after the end of the wet season to early flowering. Water requirements increase as fruit develop, reaching a peak during late fruit development.

Table 17. Mean crop factors calculated from mean soil moisture data, irrigation and rainfall inputs for three orchards over three years.

Orchard and year	Pre-flowering period (1 Apr - 1 Jul)	Flowering (8 Jul - 5 Aug)	Fruit development (12 Aug - 9 Dec)
K92	0.68	0.45	0.97
K93	0.71	1.08	1.21
K94	0.98	1.39	1.44
<i>mean</i>	<i>0.79</i>	<i>0.97</i>	<i>1.20</i>
D92	-	0.91	1.15
D93	0.79	1.28	1.43
D94	-	-	-
<i>mean</i>	<i>0.79</i>	<i>1.04</i>	<i>1.29</i>
CPRS92	0.75	0.94	1.25
CPRS93	0.66	1.02	1.10
CPRS94	-	0.94	1.11
<i>mean</i>	<i>0.71</i>	<i>0.97</i>	<i>1.15</i>
Grand Mean	0.76	0.99	1.21
SE	0.04	0.10	0.06

Table 18 summarises the seasonal changes water use pan evaporation and crop factors for rambutan grown in the Top-End of the Northern Territory.

Table 18. Seasonal changes in water use, pan evaporation and crop factor for rambutan grown in the Top-End of the NT.

Period	Average water use (mm/wk)	Average pan evaporation (mm/wk)	Crop factor (water use/evaporation)
1 Apr - 1 Jul (pre flowering)	38.00	50	0.76
8 Jul - 5 Aug (flowering - fruit set)	51.48	52	0.99
12 Aug - 9 Dec (fruit development)	67.76	56	1.21

The crop factors developed from these data and can be used to estimate water requirements for rambutans in the wet/dry tropics of northern Australia

10.4 Discussion

Information on rambutan water requirements is scarce (USDA 1979; Coronel 1983; Delabarre 1989; Tindal 1994) and is of a general nature and does not allow water requirements to be quantified. The data presented in this chapter allow water requirements to be quantified which in turn allows an improvement in irrigation management to take place.

The water requirements of tree crops can be related to evaporation from an open pan with adjustment for a crop factor (Doorenbos and Pruitt 1977). Canopy area is an important component of tree size and hence water use. Water use varies throughout the year, and is normally below the potential water loss shown from the pan. Under some circumstances (eg. rapid fruit growth) the tree may require more water than that lost from the pan. In general, the crop factor (water use of tree/evaporation from the pan) for tree crops ranges from about 0.5 - 1.4 during the year. This range was also found in the current study.

10.4.1 General irrigation recommendations

The information gleaned from this study has been used to provide irrigation recommendations to growers in the NT (Lim and Diczbalis 1995; Lim and Diczbalis 1996). The crop factors can be used to determine water requirements of rambutan grown in the NT and in other environments (Table 19).

Table 19. Calculated crop factors and water requirements, daily and weekly, for rambutan. Data based on a canopy area of 30 m².

Period	Crop factor	Evaporation rate. (mm/day)	Water requirement (mm/day)	L/tree/day	L/tree/wk
End of wet to flowering	0.76	7.1	5.4	162	1134
Flowering	0.99	7.4	7.3	219	1533
Fruit filling	1.21	8.0	9.7	291	2037
Harvest to end of wet*	1.0	6.0	6.0	180	1260

* - guesstimate.

The water requirement recommendations are given with the understanding that growers are informed that the evaporation based system of determining water requirements is a valid means of assessing water requirements for the design of new orchard irrigation systems and as a starting irrigation level in existing orchards. Day to day irrigation management should be carried out in conjunction with one of the many soil moisture monitoring instruments available.

Additional irrigation management strategies recommended to growers include the following;

- Use the crop factors supplied to calculate irrigation requirements. Note the lower crop factor can be utilised pre-flowering to stimulate flower induction and improve synchronicity of harvest.
- Due to the shallow nature of the root system, maximise the wetted area under the tree (minimum of 60 % of the canopy area).
- During the dry season, irrigate frequently (daily and possibly twice daily during fruit filling).
- Keep the area under the tree free of weeds.
- Use a mulch to minimise evaporative loss from the soil surface and improve water retention.
- Monitor soil moisture regularly with instrumentation of choice.
- Monitor watering depth; saturated soil beyond 60 cm indicates over irrigation.
- Be prepared to irrigate during a prolonged dry period (> 5 days without rain) during the wet season.

10.4.2 Pre-flowering water stress recommendations

Chapter 9 discussed the use of controlled water stress to initiate flowering in rambutan. Pre-flowering irrigation treatments which resulted in earlier and more synchronised harvests were 3.5 mm/day and 10.8 mm every 2nd day. These inputs resulted in relatively high soil moisture tensions at 20, 40 and 80 cm which is thought to be necessary to initiate flowering. The treatments of 3.5 mm/day and 10.8 mm every 2nd day imposed are equivalent to crop factors of 0.49 and 0.76 respectively. Hence crop factors in the range 0.5 to 0.76 can be utilised pre-flowering to try and promote earlier floral initiation.

10.5 Conclusion

Rambutans have shown themselves to be sensitive to drought. Relatively short periods of nil irrigation during the dry season in the NT will lead to leaf wilting and death. The work carried out in this study suggests that the sensitivity of rambutan to short periods of drought is due to two factors. Firstly, the plant has an extremely shallow root system which limits the trees access to stored soil moisture. Secondly, stomatal closure does not occur with increasing leaf to air vapour pressure deficit until relatively high VPD's (5.0 kPa) which increases the water loss during the dry season.

Managers of rambutan orchards need to be aware of the rambutans high water requirements, particularly from flowering through to harvest. Unfortunately the effects of soil moisture deficit on fruit development and final fruit size were not investigated during this project. However, it is assumed that if water deficit occur during fruit filling, fruit retention and size will be adversely affected. Irrigation management during the pre-flowering period (early April - early July) is also crucial if the date and synchrony of flowering are to be managed within the seasonal constraints of the environment (Diczbalis *et al.* Chapter 3). Given the shallow root system of the tree, soil moisture monitoring, using tensiometers, in conjunction with records of irrigation inputs is highly recommended.

10.6 References

- Coronel, R.E. (1983). Rambutan *in*: promising fruits of the Philippines. University of Philippines, Los Banos.
- Delabarre, Y. (1989). Synthese bibliographique sur le ramboutan ou litchi chevelu (*Nephelium lappaceum* L.). *Fruits*, 44:33-44, 91-98.
- Doornbos, J., and Pruitt, W.O. (1977). Crop water requirements, *in* Irrigation and drainage paper 24, Food and Agriculture Organisation. United Nations, Rome, Italy.
- Lim, T.K., and Diczbalis, Y. (1995). Rambutan. *in* Horticulture Australia, (ed.) B. Coombs, Morescope Publishing Pty, Ltd, Melbourne.
- Lim, T.K., and Diczbalis, Y. (1996). Rambutan, 2. Growing and Marketing. Agnote No. 662. NT Department of Primary Industry and Fisheries.
- Lok, J.W.D. (1988). The use of tensiometry in irrigation scheduling. *in* Proceedings of the Fourth International Micro-irrigation Congress, Volume Two, Albury-Wodonga, Australia.
- Tindall, H.D. (1994). Rambutan Cultivation. F.A.O. Plant production and protection Paper 121, Rome, Italy.
- USDA (1979). Cultivation of neglected tropical fruits with promise. Part 6. The Rambutan. US Department of Agriculture Science and Education Administration.

11.0 A study tour report of Peninsula Malaysia and Sarawak. Flowering patterns of tropical fruit in relation to environmental variables with emphasis on rambutan.

Y. Diczbalis

11.1 Introduction

Many tropical fruits from SE Asia have been introduced over the last 50 years. Intensive introduction of species has occurred over the last 10-15 years, particularly due to the interest in commercial cultivation and sale of the fruit.

Many of the species, Rambutan, Durian, Mangosteen and Carambola, are native to West and East Malaysia which experiences, high rainfall and humidity throughout the year. These species have often been introduced into an environment which has a prolonged dry season during which humidity is generally low. Within Australia, crop agronomy and maintenance has been somewhat *ad hoc* and mainly based on flowering and fruiting patterns which occur locally or are based on anecdotal experience of production patterns in the species native environment.

The aim of the study tour was to gain information on flowering and fruiting patterns of the above trees, with particular reference to rambutan, from researchers and growers in East and West Malaysia. The findings from the tour will be incorporated into future research with the aim of manipulating flowering particularly through soil water management. Information will also be used in the development of pruning, plant nutrition and other agronomic practices.

11.2 Climate

Malaysia (Peninsula) lies between 1°16' N and 6°43' N latitude. The west coast (area of study) experiences a range of rainfall from 1651 mm/yr in Perlis to 3,800 mm/yr in Taiping. The climate has been documented by Nieuwolt (1982) and a subsequent report has used Nieuwolt climate analysis to select locations suited to the growth of various crops (MARDI, 1982). These selections have been made on the premise that various crops require different levels of water stress to induce flowering.

Sarawak the largest state of Malaysia occupies the NW side of the island of Borneo (Kalimantan). Kuching (1.5°N) experiences a high (4,061 mm/yr) well distributed rainfall relative to Miri (4.5°N) which has a high rainfall (2,584 mm/yr) with a short dry season.

11.3 Rambutan

The principle crop of interest during the study was Rambutan. Rambutan is a popular crop in Malaysia and is grown extensively throughout Peninsula Malaysia and Sarawak. The State of Perlis in the NW corner of peninsula Malaysia, which experiences a regular 2-3 month dry season from December through to February, is the only State on the west coast which appears to be devoid of Rambutan.

Discussions with growers and researchers on the flowering behaviour of Rambutan, suggested that flowering was seasonal over a wide range of rainfall environments from the dry NW of

peninsula Malaysia to the wet SW of Sarawak. However, in each case flowering appeared to follow a distinct break in rainfall (Table 20).

Table 20. Onset of flowering in rambutan for a number of locations throughout Malaysia in relation to dry months.

Location		Dry Months	Usual Flowering	Harvest
Bukit Tangga	NW Malaysia	Dec-Feb	February-March	June
ADB Project	NW Malaysia	Feb-Mar	April	Late July
Taiping	Central West Malaysia	Nov-Dec	December	March
Miri	NW Sarawak	Feb-Mar / June-July	June	Sept/Oct
Kuching	SW Sarawak	June-July	July	Oct/Nov

The intensity and duration of the dry months is variable from region to region with a distinct dry (2-3 months < 50 mm/mth) occurring in Bukit Tangga and a indistinct dry occurring in Kuching and Taiping. Generally, areas with a distinct dry (3-4 weeks) are preferred for the production of Rambutan.

The synchronicity/seasonality of flowering in wetter areas such as Kuching is not completely clear. Local research workers claim a distinct seasonal flowering pattern, however, my observations during mid June suggest that plants at every stage of development were present. These stages include:

- full vegetative flush,
- part flushing, part dormant,
- dormant with minor flowering,
- part flushing, part flowering,
- full flower,
- part flower, part fruit set.

These observations were made on trees grown throughout the Kuching district, with most flowering plants occurring within the suburban/city area. Trees growing in suburban/city environments may be more responsive to short periods of no rainfall due to their restricted root zone.

Rambutan research conducted by MARDI (Malaysian Agricultural Research and Development Institute) in the seasonally dry environment of North Kedah, suggest synchronous seasonal flowering is achievable through;

- light annual pruning (following harvest),
- regular fertiliser application, 4 times/year, (post pruning and 3 monthly),
- irrigation when required to encourage even vegetative development,

- irrigation withdrawn during the preflowering dry season,
- removal of excess fruit at harvest time.'

These agronomic measures also reduce bienniality which is reported to occur in a large number of clones, particularly R7, R99, R153, R163, R168 and R185. The bienniality occurred more on individual shoots, rather than on the tree as a whole.

Tree size control was another issue emerging in Malaysia, particularly as production was becoming more intensive and moving away from the Kampong (Village). Regular pruning after harvest was seen as the major solution, although, heavy pruning (3-4 whorls back from the panicle) was not recommended on a yearly basis. There was some interest in rootstock-scion combinations which may reduce tree size, however, no solutions were currently at hand. In Sarawak some work had been undertaken using *Dimocarpus* (longan) species as a rootstock. The union was apparently successful, however, there were no reports on its usefulness in reducing tree size or its long term effect on tree longevity and productivity. The trees sensitivity to drought as experienced in the NT is not as evident in Malaysia. A number of researchers mentioned that trees survive periods of drought up to 20 dry days without any symptoms of leaf drop. A number of factors would contribute to the rambutans hardiness in its native environment. These include:

- soil high in clay and hence water holding capacity,
- low sunshine hours (< 8.5 hours),
- high average relative humidity (> 75%).
- low daily evaporation rate (< 5.0 mm/day).

Root distribution, although not measured, is said to be shallow as per findings in the NT.

A major area of research is plant selection. At the MARDI Fruit Research Station in Bukit Tangga (N. Keddah) a large hybridisation trial was in its fourth year in 1984. Over 5,400 seedlings of an open pollinated cross of 16 parents are being evaluated for earliness, yield and fruit quality. A number of promising lines have been identified which will be confirmed in the next two to three seasons.

11.4 Durian

Durian is the fruit crop of major importance in both peninsula Malaysia and Sarawak. A large research effort has been directed toward the crop principally in the following areas:

- Varietal selection,
- plant breeding/hybridisation,
- disease (phytoptera) control,
- legume pasture intercrop,
- rootstock (particularly other species of Durio),
- effect of topping height on growth and yield,
- single and double rootstock,
- effect of secondary and tertiary branching on production.

Current popular clones include D24 (considered the supreme clone), D99, D2, D96, D2, D8. A number of Thai clones are grown, however, they are considered inferior to the Malay material.

The Malay Durian tend to be small in size and range from 0.8-1.5 kg in size. The price of premium clone durians is high and ranges from \$5-8 per kg. Less highly regarded material can be purchased for substantially less. Flesh and seeds extracted from the fruit and packed in a cling wrap styrofoam tray sold for \$10-20/kg. The flowering and fruiting characteristics of Durian are also related to local climate, with flowering being induced by a dry period. The intensity and duration of the dry period is not known, although MARDI recommendations suggest a maximum of three weeks. The flowering pattern for various regions in Malaysia is similar to that for Rambutan (Table 20).

Durian is reported to be extremely sensitive to drought and all major new plantings include irrigation. Young trees (less than 3 years) would be irrigated following 1 day without rain. Older trees are irrigated after 3 to 4 days without rain, except during the pre-flowering dry period.

In wetter areas such as Kuching, durian flowering is less regular due to the poorly pronounced dry season. The extent of flowering is reportedly dependent on the duration of the dry period. The comment made by a grower in Miri confirmed the requirement for a dry period.

Mr Chai - Durian grower Miri -

"The flowering is poor this year as there has not been a distinct dry season - too much rain".

11.5 Mangosteen

Mangosteen are an important fruit in Malaysia. The trees are extensively grown throughout the country, with the majority of plants occurring around villages. I observed few commercial plantings and where they existed they were a minor part of the overall orchard. The research effort into Mangosteen was relatively high with particular emphasis on:

- reduction of juvenility,
- phenology monitoring,
- grafting trials,
- trellising trials.

Mangosteen is a relatively low priced fruit (< \$1.60/kg) and the research work appeared to concentrate on improving the efficiency of production. Particularly in terms of reducing the juvenile period (which is in the vicinity of 6-8 years). Non-shaded plantings were seen to offer earlier production possibilities.

Grafted plants were problematic in that plants remained small and productivity was generally low. The selection of scion wood is seen as being important in determining the level of apical dominance in the grafted plants. Scion wood from side branches resulted in plants with a sprawling habit, whereas, scion wood from apically dominant upper branches resulted in a tree with improved height and structure. In general grafted plants were not seen as the solution to juvenile period reduction as the reduced productivity negated any advantages offered by earlier production.

The flowering behaviour of mangosteen was also reported to be influenced by a dry period. Three to four weeks of mild moisture stress was regarded as the necessary induction period.

Although not fully investigated, the flowering times in relation to regions are similar to rambutan as in Table 20.

11.6 Carambola

Carambola is a popular crop which was said to command a relatively high price. Two commercial orchards were visited, as well as a MARDI commercial planting. In all cases the varieties were B10 and B17, using B2 as the male pollinator. Plants were generally planted at a 6.0 x 6.0 m spacing and pruned to give a predominance of lateral growth. Orchards were very productive, however, they were extremely labour intensive as fruit were bagged (paper or plastic) for protection against fruit fly. Fruit size and quality were good although the fruit from the orchard in the Taiping area (high rainfall) appeared to suffer from a rust like pathogen. Flowering occurred throughout the year with a number of major production cycles.

Fertiliser (12.12.21) was applied fortnightly.

11.7 Guava

Guava was a popular crop and a number of orchards were visited throughout the trip. Flowering and fruiting occurred throughout the year. High density plantings were popular and the crop was extremely labour intensive due to the necessity to bag fruit against fruit fly attack.

At the MARDI Station in Kuala Kangsar, a guava selection project was underway. The parent fruit (seed) had been irradiated at four levels (5, 10, 15 and 20 rad). Some 2,000 plants were being evaluated for yield, earliness and fruit quality. There was no indication given as to whether any useful lines had been identified.

11.8 Papaya

Papaya was another crop which fruited throughout the year. The variety *exotica* was extremely popular, although it produced a very small fruit (double pair size). The MARDI Station at Kuala Kangsar produced seed for commercial growers @ \$1,630/kg.

Many commercial plantings of Papaya were irrigated using T-Tape.

11.9 Mango

Mango is a popular crop with an increasing number of commercial orchards. The majority of plantings are in the State of Perlis (NW corner of peninsula Malaysia) which has the longest dry season. A pronounced dry spell is required to initiate an even synchronous flowering. The dry months are December, January and February (rainfall < 50 mm/mth). Flowering normally occurs in mid January with April the main harvesting month. The main varieties are Nam Dok Mai, Golek and Maha. Other popular varieties are Chok anan, Mon Diam Kow and Harimanus.

The major problems associated with mango production in Malaysia is flowering, particularly when grown in districts with a non distinct dry season. Trees tend to flower regularly when young (<5 years old) however, with age flowering becomes less synchronous and seasonal. The relationship between soil moisture and flowering is further strengthened by the fact that mangoes which are grown on rice bunds are generally the first to flower when the water is

drained away at the onset of the dry season. Some researchers believe the rate of onset of stress may also play an important role in the flowering stimulus, with a rapid onset of stress triggering flowering as for the trees grown on rice bunds.

Fruit quality is another major problem with Malaysian mangoes, both internal fruit break down and external peel quality. The peel quality problems are associated with the high rainfall that occurs during most of the first development phase. Clean fruit are a rarity. Internal fruit breakdowns are thought to be related to nutrient imbalances in fruit, particularly those with high N and low Ca.

A number of the varieties grown (Mon Diam Kow, Nam Doc Mei and Chok Anan) are considered dwarf trees. They are generally grown at higher densities (8.0 x 4.0 m). Both Chok Anan and Mon Diam Kow appeared to be very productive varieties with panicles commonly holding 4-6 fruit. Most of the varieties are grafted on to a common malay rootstock "Telor" (*Mangifera laurina*) which is reported to be a small statured plant bearing egg size fruit.

11.10 Conclusions

Flowering in rambutan, durian, mangosteen and mango is promoted by a distinct dry season. The length of the dry required to trigger flowering is not known. However, flowering patterns in areas such as Kuching (Sarawak), which does not have a distinct dry season, suggest that only short periods without rain are sufficient to trigger flowering. The strength of the flowering response is thought to be linked to the length of the dry period. Hence, areas which do experience a regular and distinct dry season are preferred for the commercial cultivation of the above crops.

11.11 Acknowledgments

This trip would not have been possible without the support of RIRDC and NT DPIF. My grateful thanks to Dr. Razak Bin Sharri of MARDI and Mr. Voon Boon Hoe of the Sarawak Department of Agriculture for organising and supplying the logistic support in mainland Malaysia and Sarawak.

I would also like to extend my thanks to the many researchers and growers who gave up their time to share their knowledge of tropical fruit growing with me.

11.12 Malaysian Agricultural Research Officers and Growers - Contacted.

Name	Position		Location
<u>MARDI</u>			
Dr Mohamad B Osman	Director	Fruit Research	Serdang
Dr Razak B Sharri	Head	Fruit Research	Bukit Tinggi
Mr Zainol Abd Aziz	Senior Research Scientist	Basic Research	Serdang
Mr TG Ab. Malik	Mango Research	Fruit Research	Bukit Tinggi
Mr Ab. Ghani	Durian & Rambutan	Fruit Research	Bukit Tinggi
Mr Mahsri	Mangosteen	Fruit Research	Bukit Tinggi
Mr Ko Weng Wah	Plant Pathologist	Fruit Research	Bukit Tinggi
Mr Subki HJ Ahmed	Technical Officer Guava, Mangosteen, Durian	Fruit Research	Kuala Kangsar
Mr Burhan Taib	Senior Technical Officer Durian, Mangosteen, Carambola	Fruit Research	Kuala Kangsar
Mr Zaidaie	Technical Officer Durian	Fruit Research	Kuala Kangsar
Mr Khazir Darus	Development Officer		Kangar
Mr Harun	Development Officer		Langkawi
<u>Asian Development Bank Project</u>			
Mr Talib	Project Manager		Baling (Kedah)
<u>Kedah Department of Agriculture</u>			
Mr Salehuddin Yahya	Extension Officer		Alor Setar

Name	Position	Location
<u>Sarawak Department of Agriculture</u>		
Mr Julhai	Director Agriculture	Kuching
Mr Lim Chin Pang	Assistant Director (Research)	Kuching
Mr Voon Boon Hoe	Agronomist - Fruit Research	Semongok
Mr Kueh Hong Siong	Senior Research Officer	Semongok
Mr Ng Thai Tsiung	Agronomist - Upland Agriculture	Semongok
Mr Teo Chan Hock	Plant Pathologist	Semongok
Mr Lau Cheng Yuon	Agronomist - Tree Crops	Semongok
Mr Chai Cheng Chong	Agronomist - Vegetables	Semongok
Dr Rita	Agronomist - Tissue Culture	Semongok
<u>Private Orchards</u>		
Mr Fong Swee Keng	Fong Nursery & Mango Plantation (Dwarf Mango Clones)	Bidor
Mr Abdul Rahim	Carambola Grower	Taiping
Mr Gan Chong Ho	Perlis Plantation - Manager (Mango)	Kangar
Mr Chai	Durian Orchard	Miri
Manager	Ladang Eden (Durian Orchard)	Tapah
<u>ACIAR</u>		
Ms Jean Sambhi	Manager (Malaysia)	Kuala Lumpur

11.13 List of Publications Collected

Papers

Ghani, M.A. and Selleh, dan H. (Draft). Rambutan: The problems of bieniality and control measures. In Malay with English Abstract.

Tarmizi, S. Ahmad *et.al.* (1993). Incidence of insidious fruit rot as related to mineral nutrients in Harumanis mangoes. MARDI Research Journal, 21: 43-49.

Publications (English)

Nieuwolt, S. (1982). Climate and Agricultural planning in Peninsula Malaysia.

Mohamad, O. and Chan, Y.K. (1992). Generating technology for commercial cultivation of fruits. MARDI, Fruit Research Division.

Norlia, Y. *et.al.* (1992). Technology for commercial production of melons. MARDI, Fruit Research Division.

Nik Masdek, N.H. *et.al.* (1992). Commercial production of planting material. MARDI, Fruit Research Division.

Salma, I. and Masrom, H. (1992). A systematic description of mango clones in Peninsula Malaysia. MARDI, Report No. 151.

Lam, P.F. (1991) Handling and storage of payaya. Siri Maklumat No. 23.

Lam, P.F. (1991) Handling and storage of mangoes. Siri Maklumat No. 26.

Lam, P.F. (1991) Handling and storage of starfruit. Siri Maklumat No. 28.

Hassan, A. *et.al.* (1988) Storage of local fruits. Maklumat No. 19A.

Lam, P.F. (1991) Handling and storage of rambutan. Siri Maklumat No. 24.

Anon. (1991). Research Branch Department of Agriculture, Sarawak, Annual Report.

Nieuwolt, S. (19__). Agricultural droughts in Peninsula Malaysia. MARDI.

Department of Agriculture, Sarawak (1992). 29th Research Officers Annual Conference, Proceedings of the technical sessions. Research Branch, Dept. of Agriculture, Sarawak.

Anon. (1993). Kabuloh - An integrated agricultural station of Northern Sarawak, Jabaton Pertanian Sarawak.

Publications (Malay)

Khalid, M.Z. and Rukayah, A. (1993) Penanaman Manggis. MARDI.

Anon. (1992). Penyelidikan Buah-buahan. MARDI.

Anon. (1989). Pengendalian belimbing untak eksport ke Eropah. MARDI.

Abidin, M.Z. *et.al.* (1991). Penanaman durian. MARDI.

Anon. (1993). MARDI Publications Catalogue. Maklumat Dan pembangunan Seiring Jalan.

11.14 Itinerary

28 May 1994		Darwin to Kuala Lumpur (K.L.)
29 May		K.L. - Free Day
30 May	a.m.	Meet Dr Razaak and Mr Ghani. Drive to MARDI (Serdang) HQ of Fruit Research Division. Held discussion with MARDI researchers and tour orchard.
	p.m.	Drive to Cameron Highlands and overnight.
31 May	a.m.	Tour MARDI (Cameron Highlands) Research Station. Vegetable temperate fruit production and flower production. Visit Ladang Edan (Durian orchard) at foothills of Cameron Highlands.
	p.m.	Visit Fong Nursery and Mango farm, Bidor area Producer of Thai dwarf mango clones. Owner Mr Fong Swee Keng. Drive to Ipoh and overnight.
1 June	a.m.	Tour MARDI (Kuala Kangsar) Research Station. Mangosteen, Durian, Guava and PawPaw research. Discussions with Burhan Taib and Subki Ahmad. Visit Carambola farm (Owner: Mr Abdul Rahim). Producer of B10 and B17 Carambola.
	p.m.	Visit rambutan farm (3.5 ha) Vr. Deli (local selection). Unable to meet manager. Drive to Penang Is. and overnight Georgetown.
2 June	a.m.	Tour fruit production areas of Penang Is. Observe Durian, Rambutan and Mangosteen trees in the Balik Pulau area. Drive to Sungai Petanic (Kedдах State).
	p.m.	Visit Kampong rambutan orchard based on R193 (Dept. of Ag. release). Visit two Asian Development Bank Projects centred on the production of Durian, Rambutan, Coffee (robusta) and Rubber in the Baling area. Drive to Alor Setor and overnight.
3 June	a.m.	Drive to Perlis (State) and visit Perlis Plantations (mango) near Chuping. Manager: Mr Gan Chong Ho (18,000 tree orchard).
	p.m.	Visit MARDI (Kangar) Development Station. Discussions with Mr Khazir Darus (Development Officer). Tour Banana plantation (vr. Berangan). Tour State subsidised Carambola plantation. Drive to Kuala Perehis and catch ferry to Kuah, Langkawi Is. Overnight Langkawi.

- 4 June a.m. Visit MARDI (Langkawi) Development Station. Tour Guava, Mango, Carambola, PawPaw and vegetable growing sites. Station Manager: Mr Harum.
Discussion on flowering in relation to local weather.
- p.m. Free
Catch ferry from Kuah to Kuala Kedah. Drive to Alor Setaor and overnight.
- 5 June a.m./p.m Drive to MARDI Fruit Research Station (Bukit Tangga). Discussions with station leader Dr Razak and fellow researchers.
Tour experimental sites.
Deliver seminar on "Irrigation Management of Horticulture Crops in NT".
Further discussions.
Drive to Alor Setor and catch flight to Kuala Lumpur. Overnight K.L.
- 6 June a.m. Drive to MARDI HQ (Serdang). Meet Director of Fruit Research Dr Mohamad.
Visit MARDI Publications Section and select books on fruit cultivation.
- p.m. Free
Overnight K.L.
- 7 June a.m. Fly to Kuching, Sarawak met by Mr Lau Cheng Yuon (Sarawak Dept. of Agriculture). Arrange ticket for Miri/Mulu/Kuching flight.
- p.m. Free
Overnight Kuching.

- 8 June a.m. Fly to Miri. Met by Mr Stembridge Ho.
Tour Durian plantation. Owner Mr Chai.
- p.m. Visit local vegetable producing farms.
Overnight Miri.
- 9 June a.m. Fly to Mulu. Visit Dept. of Agriculture Batu Bangan Peran Project. An Attempt by Sarawak Dept. of Agriculture to introduce nomadic Penan peoples to cultivation of rice and fruit.
Overnight project site.
- 10 June a.m. Discussions with project co-ordinator (Mr Voon) on project and possible areas of improvement.
- p.m. Fly Mulu to Miri.
Visit Sarawak Department of Agriculture, Kebuloh Research Station inspect Rambutan and Durian plots.
Visit Salak farm south of Miri (60 km)
Return to Miri and overnight.
- 11 June a.m. Fly Miri to Kuching
Free Day
Kuching overnight
- 12 June a.m. Visit local Sunday market with Mr Voon Boon Hoe.
- p.m. Free
Kuching overnight.
- 13 June a.m. Pay courtesy call to Director, Sarawak Dept. of Agriculture (En Jubiahu) and Assistant Director Research (Mr Lim Chin Pang).
Drive to Somkock Agriculture Research Centre and hold discussions with staff.
- p.m. Drive to Tarat Research Station and tour Durian, Mangosteen and Rambutan sites.
- 14 June a.m. Present Seminar on "Irrigation Management of Horticultural Crops in the NT". Discussions on possible collaborative work.
- p.m. Visit Sarawak Cultural Village.
Overnight Kuching.

15 June	a.m.	Prepare plants for importation into Australia.
	p.m.	Visit Rockmelon farm. Overnight Kuching.
16 June	a.m.	Drive to Rampangi (Acid Sulphate Soil) Research Station and inspect Mango, vegetables and Salak trials.
	p.m.	Drive to airport and fly to Kuala Lumpur.
17 June	a.m.	Meeting with Jean Sambhi (ACIAR Manager Malaysia)
	p.m.	Free Fly to Darwin.

Part Two

Environmental Factors Influencing the Growth and Yield of Cupuacu (*Theobroma grandiflorum* (Wild. ex Spreng.)) in the Wet/Dry Tropics of Northern Australia.

1.0 The growth and yield of Cupuacu (*Theobroma grandiflorum*), a possible chocolate alternative, in the Top-End of the Northern Territory, Australia.

Y. Diczbalis, G. McMahon and C. Wicks

1.1 Introduction

The cupuacu (or cupuassu), *Theobroma grandiflorum*, is a tree growing wild in the Eastern Amazonia (Clement and Venturieri, 1990). The species is of the same genus as cocoa, *Theobroma cacao*. It is now being domesticated and cultivated in the eastern Amazon region, where it is frequently planted in gardens or small farms. Correa (1984) states that Cupuacu is grown commercially in 10 states of northern Brazil. The annual production of cupuacu pulp from Acre state alone is 350 tonnes (Laker and Trevisan, 1992). Domestication of the species, involving development of production and processing technology, to commercialise the crop, has been investigated since the early 80's in South America.

The crop was introduced into northern Australia in 1991 as a potential "new crop" due to its possible confectionery uses. Cupulate, the chocolate like product made from fermented and roasted Cupuacu beans, is reportedly free of theobromine and caffeine which are both stimulants found in cocoa based chocolates and hence the processed material may have potential for use in "health related" alternative chocolate products (Duncan and Ascenso, 1990).

1.2 Literature Review

1.2.1 Uses

The fruits, commonly called pods, are some-what larger than those of cocoa and rounder in shape, and unlike cocoa, the pods fall from the tree at maturity which lends itself to mechanical harvesting. The epicarp is hard and woody, and the seeds are surrounded by a tasty and agreeably scented pulp. Apart from the utilisation of the pulp for juice, nectar and other by-products, Venturieri and Aguiar (1988 as cited by Clement and Venturieri 1990) suggest the seeds can be used to make a chocolate substitute known as 'cupulate'. The reported chocolate like quality of 'cupulate', as well as the many by-products made from the pulp indicate the potential of cupuacu as an industrial crop.

South America reportedly exports frozen pulp to Europe and Japan, but demand cannot be fully met. Supply is limited, as there are still no large scale commercial cupuacu plantations (Duncan and Ascenso, 1990).

Calzavara (1970, cited by Clement and Venturieri 1990) states that a major Swiss chocolate manufacturer was interested in the fabrication of white chocolate from cupuacu, but the supply of seed and cupuacu butter was too limited. Should production of this crop be developed and the cupulate and "by products" found to be useable by the confectionery industry, the industrialisation of the crop could be quite feasible.

1.2.2 Botany

1.2.2.1 Classification

The cupuacu, *Theobroma grandiflorum*, is a member of the Sterculiaceae family. This is a large family of tropical and sub tropical trees, shrubs, and herbs. The most economically important member of this family is *Theobroma cacao*, from which cocoa is produced, and *Cola acuminata*, and *C. nitida*, from which caffeine is obtained. Australian members of this family include the Illawarra flame tree, *Brachychiton acerifolius*, and the red-flowered kurrajong, *B. paradoxum*.

1.2.2.2 Description

Cupuacu is a small to medium sized evergreen tree, 6-10m; dark brown to greyish bark with a granular, fissured texture (Plate 5). Growth habit is pseudo-apical, with lateral branches in three's, the apical shoot aborting, and being replaced by development at the bud above one of the lateral branches, older branches becoming horizontal or descending (Clement and Venturieri, 1990).

1.2.2.3 Leaf Structure

Leaves are coriaceous, alternate, distichous, and simple. Stipules are persistent, ablong to lanceolate-oblong, 10-20 mm long and 3-6 mm wide. Petioles are 7-14 mm long and densely hairy; blades oblong to elliptic-oblong, 150-600 mm long, 50-160 mm wide; apex acuminate; base rounded or obtuse; margins entire or sinuate towards the apex (Plate 6). Leaves are usually slightly glossy, dark green above, pale grey-green to brown below, minutely hairy between the veins, which consist of 9-10 pairs directed forwards at an angle at 40°. Young leaves are brown to dark pink, and densely hairy.

1.2.2.4 Inflorescences

Flowers are small, but large relative to cocoa, axillary along the branches, with a few hermaphrodite flowers, short peduncles bearing at the apex three small bracts 3-4 mm long, pedicels 5-20 mm long (Plate 7). The following floral description is from Duncan and Ascenso (1990). Calyx divided almost to the base into 3-5, slightly boat shaped deltoid-acute lobes, 14-15 mm long, 6-8 mm wide, fleshy and tomentose. Arranged in a star shape with fine woolly hairs outside, greenish rusty or reddish within. There are five petals, which are fleshy, hooded and whitish in colour with seven ribs, 6-7 mm long, 4-6 mm wide. The blade is dark red or crimson, obcordate, 4-9 mm long, 4.5-8.5 mm wide and abruptly contracted at the base. The androecium tube is short, 2.5 mm long, with five spreading lanceolate-acute staminodes 9-15 mm long, dark red and pilose outside, alternating with five shorter stamens, with filaments 1.7-2.0 mm long, each bearing at the apex three bi-ocular anthers. Ovary pentagonal-obovate, five locular, each with numerous ovules. Style slender 2 mm long, free to the base (Plate 8).

1.2.2.5 Fruit

Fruits are oblong to obovoid-ellipsoid, large, 15-40cm long, 10-15cm in diameter, weighing from 1.0-1.5 kg up to 4 kg, rounded at both ends, smooth, thinly covered with brown hairs. Fruit falls from the tree at maturity without the peduncle attached. Pericarp is hard and 10 mm thick, with a hard woody shell, or exocarp, 2 mm thick. Mesocarp is 5-7 mm thick, fleshy at maturity with a thin membrane surrounding the seed cavity (Plate 9).

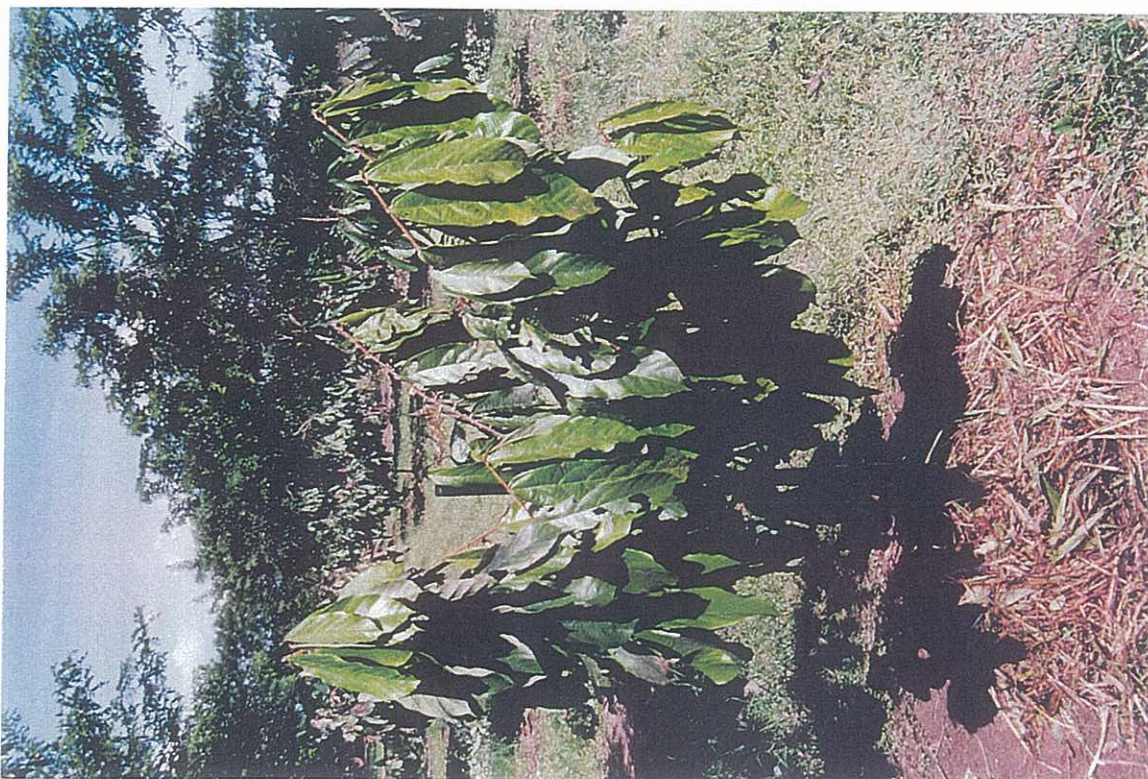


Plate 5. A two year old cupuacu tree with shade trees (*Glyricidia sepium*) in the background, at Coastal Plains Research Station.



Plate 6. Cupuacu leaves.



Plate 7. Cupuacu flower.



Plate 8 Enlarged view of a Cupuacu flower showing, petals, androecium, stamens and style.



Plate 9. Cupuacu pod attached to the tree

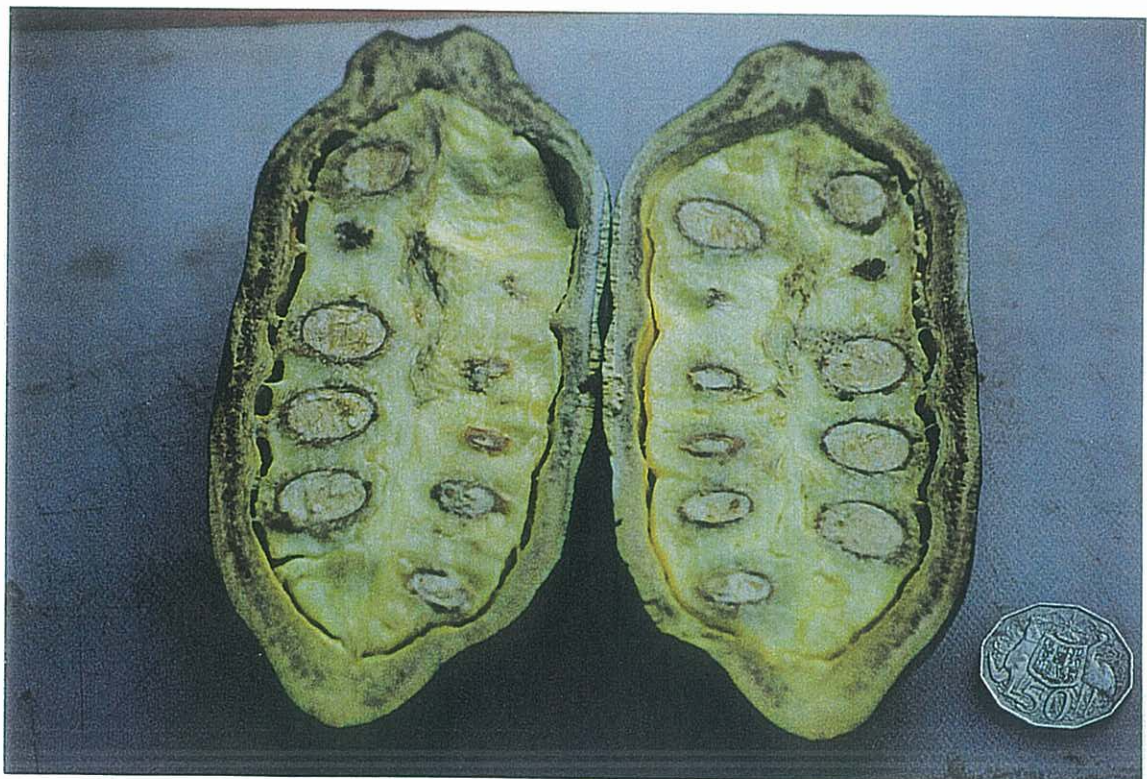


Plate 10. A longitudinal view of a cupuacu pod showing the pod wall, pulp and seed.

1.2.2.6 Seed

Seeds number from 20-60 per pod, and are 20-30 mm long, 20-25 mm broad, and 10-12 mm thick. Arranged in five rows they are thin-skinned, nut-brown to reddish, and enveloped in a fibrous, creamy white to creamy yellow, rather juicy, but firm, pulp with a distinct strong aroma and is slightly acid in taste (Plate 10). Germination is hypogeous, and the embryo is white marbled with white cotyledons. The seedling has a central tap root and ramifying branches. At maturity the tap root never exceeds 2 m long and the lateral roots are mainly superficial (Duncan and Ascenso, 1990).

1.2.3 Environmental Requirements

1.2.3.1 Distribution

Cupuacu originated in the rain forests of eastern Amazonia in Brazil, where it is still found growing wild (Laker and Trevisan, 1992). It has now spread throughout Brazil and into many areas of the humid tropics of South America. At present it is grown as a garden or small farm planting, though there are some commercial plantings in tropical American countries such as, Brazil, Columbia, Venezuela, Equador, Costa Rica and Peru. Cupuacu is also found worldwide in tropical botanical gardens and agricultural research stations (Duncan and Ascenso, 1990).

1.2.3.2 Climate

Although climatic requirements for Cupuacu are not precisely known, Duncan and Ascenso (1990) report that annual rainfall should be above 1000 mm, and fairly well distributed throughout the year. In areas where cupuacu occurs wild and/or cropped, rainfall may be lower than 100 mm in one to six months of the year. The range of monthly means is 24-28°C, and mean monthly maximum temperatures may vary between 29° and 36°C, and minima between 17° and 25°C. Mean annual relative humidity is 77-88%, and the range of monthly means is 64-93%. Annual insolation is 2000-2800 hours. In its natural distribution Cupuacu does not occur above 400m, but it is known to grow and fruit at 600m.

1.2.3.3 Soils

Venturieri et al. (1985, as cited by Laker and Venturieri, 1992) report that cupuacu prefers deep fertile sandy-clay soils with good water holding capacity. It also performs satisfactorily in low-fertility soils such as latasols and allic red podzols, but will only produce high yields with regular fertiliser applications (Duncan and Ascenso, 1990).

1.2.4 Growth Habits

Cupuacu is an erect tree, 6-8 m high when cultivated (Clement and Venturieri, 1990). Seedling trees begin to bear in the third year after planting, but variation to this has been observed. Yields increase with age and stabilise around the 10th year or earlier. Young grafted trees begin fruiting in their second year, and some genotypes may start bearing a few months after grafting. Early bearing may be promoted by removing all first flowers.

In the Amazon region, variation in the timing and length of flowering and fruiting has been recorded. Flowers tend to open slowly, mostly in the morning, and don't close again. Flowering time and length varies from tree to tree, with the individual tree flowering period

extending from two to over three months. Laker and Trevisan, (1992) report that in the Brazilian states of Amazonas and Rondonia, Cupuacu flowers from June to March with peaks between November and January. Peak pod production occurs during February and June. Pods mature some four to four and a half months after flowering and fall to the ground from where they are collected.

Falcao and Lleras (1983, cited by Clement and Venturieri, 1990) studied seven year old trees and found that they produce about 3 500 flowers annually, most of which are produced in the dry season. Final fruit set varies between 1 and 2% depending upon nutritional maintenance. This low efficiency in the flowering/fruitletting process is also apparent in cocoa and other fruit crop species

It has been indicated that several species of bees, flies, ants and aphids are the likely pollinating agents for Cupuacu. Bagged flowers are not pollinated and do not set fruit, which indicates an allogamous breeding system (Duncan and Ascenso, 1990). This promotes considerable intra-specific variation of major characteristics, such as, tree growth, fruit shape and size, and yield.

Calzavara (1987, cited by Laker and Trevisan, 1992) reports that three major cultivars have been recognised, these being:

- ‘Round Cupuacu’ (redondo) which has pods of an average weight of 1.5 kg which are rounded at both ends and has a husk thickness of 6-7 mm;
- ‘Large cupuacu’ (mamorana) with an average pod weight of 2.5 kg, often up to 4 kg, and large pointed fruit with a husk thickness of 7-9 mm;
- ‘Seedless Cupuacu’ (mamau), is a well defined cultivar which resulted from a spontaneous mutation. Average weight of the pods is 2.3 kg of which 67% is pulp.

The Seedless variety has almost twice the amount of pulp as the seeded varieties. It appears there is considerable scope for selection for yield depending on the main object of production.

1.2.5 *Cultural Practices*

1.2.5.1 *Propagation*

Propagation can be either from seed or vegetative multiplication (Duncan and Ascenso, 1990). Seed should be collected from healthy, relatively small high-yielding trees, and should be planted as soon as possible because they quickly lose their viability. Seeds are carefully removed from the pulp and cleaned by rubbing in dry sawdust, and washing in water to remove any remaining pulp. Seed should then be dried and treated with a copper fungicide before sowing. If it is necessary to store the seed, they can be stored for up to two weeks, when placed in slightly moist sawdust. Once washed, seeds show considerable individual variation in size, shape and appearance. The larger heavier seeds are selected for sowing as they give higher germination percentages and the seedlings are more vigorous.

Seeds can be pre-germinated by placing them in layers, and keeping them moist and under shade, until the first rootlet appears, usually after 6-8 days. The seeds are then sown 10-15 mm deep in polybags scar end down, and germination occurs after 12-17 days.

No standard growing medium has been developed for growing Cupuacu, but a mix rich in organic matter and well drained is recommended. An application of triple superphosphate, or NPK plus trace elements, is suggested at planting, and at three months an application of urea has been suggested as being beneficial. Salinity in either the soil mix or the water should be avoided.

Seedlings are ready to be planted out in the field at seven months of age. By this stage seedlings have not yet branched and are about 0.8 m high, having around 30 leaves.

1.2.5.2 Vegetative Propagation

Because Cupuacu is actively cross pollinated it displays a wide variation in prominent characteristics, such as growth, yield and quality. There is ample scope for successful genetic improvement through vegetative means. Duncan and Ascenso (1990), report that vegetative propagation methods are being used to develop suitable cultivars in order to improve crop yields. Budding and grafting techniques have been successfully tested, using Cupuacu seedlings as rootstocks. Seedlings used are 0.5-0.6 m tall and 10 mm in diameter, although older rootstocks are sometimes preferred. Budding is preferred to grafting due to a greater economy of vegetative material.

Budding

The patch budding technique is mostly used, or the variation to this, the modified Forkert method. Each method is wrapped in PVC grafting tape, which is removed after three weeks. Precuring, by removing leaves and terminal shoots of the scion 8-10 days before budding has been suggested to improve bud elongation.

Grafting

The wedge or cleft grafting technique is successfully used. The scion in this method can be the same diameter, or a smaller diameter than the stock. The splice graft gives similar results and is a good method to use if the scion and stock are the same diameter. These two methods have shown to be the most successful, giving the highest percentage 'take'. However the side veneer grafting technique has also recorded good results in Cupuacu, using terminal shoots as scion wood.

Protection against desiccation is essential. The scion is covered immediately after the grafting procedure, with a narrow transparent polythene bag, which is kept in place for 40 days, or until the new leaves are about 50 mm long. The graft union may not need to be wrapped, but simply held together with a plastic clothes peg. The grafted trees should be kept moist and under moderate shade, avoiding direct sunlight. Different lengths of scion have been tried, and generally the longer scions proved to be more successful. No distinct rootstocks have yet been selected for Cupuacu, however, good uniform seedlings are successfully being used at this stage. Grafted trees are ready to plant out in the field when they reach 80 cm high or about 7-8 months of age. Planting should preferably take place at the beginning of the wet season.

1.2.6 Orchard Management

1.2.6.1 Spacings

Tree spacings in the orchard depends on whether seedling or grafted trees are planted (Venturieri and Alves 1984). The recommended spacing for seedlings is 8 x 8 m in

either a square or quincunx arrangement. For grafted trees a 6 x 6 m square arrangement, or a 7 x 7 m or 6 x 6 m for a quincunx arrangement, the latter being preferred.

1.2.6.2 Planting

Planting holes are dug and a mix of animal manure or chicken manure with 50 g of triple superphosphate, is mixed with the top soil. The hole is backfilled and the young tree is placed into the hole. Once the polybag has been removed, the hole can be filled and the tree is well watered. Mulch is placed around the tree to reduce water loss and to control weeds.

1.2.6.3 Shading

In the early stages of establishment Cupuacu plantings require shade. In Brazil temporary shade plants are established prior so that they provide approximately 25-50% shade at planting. Once the Cupuacu is established the shade can gradually be thinned until the fourth year when it is eliminated. Venturieri and Alves (1985, cited by Velho et al. 1988) recommend shade plants include bananas and casava. as well as permanent shade such as, *Inga cinammonea* and *Inga edulis*, which is grown as a shade tree for coffee in Brazil. Others include *Spondias lutea*, and some species of palms including *Bactris gasipaes* and *Cocus nucifera*.

1.2.6.4 Weeding and Pruning

Trees should be kept clear of weeds to avoid competition, and also allow for easier harvesting. Mulch should be used under trees to prevent weeds growing and also helps to retain soil moisture.

Calzavara (1987, cited by Laker and Trevisan, 1992) suggests that young trees should have their lower branches lopped off to a height of 1.5 m, allowing a single straight trunk to develop. This promotes a better shaped tree, and assists aeration in amongst the canopy. It also makes it easier to collect pods from under the trees when harvesting. Adult trees only require the removal of dead or diseased branches, which is done after harvesting.

1.2.6.5 Fertilising

Cupuacu responds well to fertiliser, as it promotes faster vegetative growth and induces earlier bearing. The following rates are recommended by Duncan and Ascenso (1990):

Young vigorously growing trees are fertilised with, 300-600 g/tree/year of NPK 12:12:12 plus Mg. This is split into three applications yearly. In bearing orchards it is recommended to use, 300-600g/tree/year of NPK 15:15:23 plus Mg. This is applied in three applications during the year. Venturieri et al. (1985, cited by Laker and Trevisan, 1992) suggests that Cupuacu responds well to supplementations of animal manure or chicken manure.

1.2.6.6 Pests and Diseases

In the Amazon region the most serious disease is (*Crinipellis pernicioso*) witches broom disease (Clement and Venturieri, 1990). Control measures include pruning and burning affected branches and pods and spraying with a copper fungicide. Goncalves (1965) reported that Cupuacu acts as a source of inoculum for witches broom disease

in cocoa. Other problems include Phytophthora, Anthracnose and other diseases of Cocoa. Most of these can be treated with a copper spray.

Insect pests include several species of beetles, some leaf eating ants, aphids, termites and grasshoppers all of which are relatively easy to control.

1.2.6.7 Harvesting and Yields

The pods will drop from the tree when ripe, and are picked up from the ground. Frequent harvesting is necessary to prevent fungal infection or borer attack of fallen pods. Pods may break when they fall from the tree, in which case they are spoilt if not picked up almost immediately. In Brazil, fruits are harvested about 4 months after flowering. Laker and Trevisan (1992) report that in the Brazillian states of Amazonas and Rondonia, cupuacu flowers during June to March with peaks between November and January. Peak pod production occurs during February and June.

Venturieri et al. (1985, as cited by Laker and Trevisan, 1992) estimates that in a well maintained orchard, pod production per hectare can be 400, 4,000 and 9,000 in the second, fifth and ninth years respectively. On average trees produce 20-30 pods at 4-5 years of age and up to 70 pods per tree after seven years of age. At an average pod weight of 1.0 kg the potential yields are 0.4, 4 and 9 tonnes per hectare for two, five and nine year old trees respectively.

1.2.7 Marketing

1.2.7.1 Product

The pods of the Cupuacu, contain fleshy pulp and seeds (beans), both of which can be processed and used. Calzavara *et al.* (1984, as cited by Velho. et al. 1988) indicate that the fruit has a wide variety of uses (Figure 30).

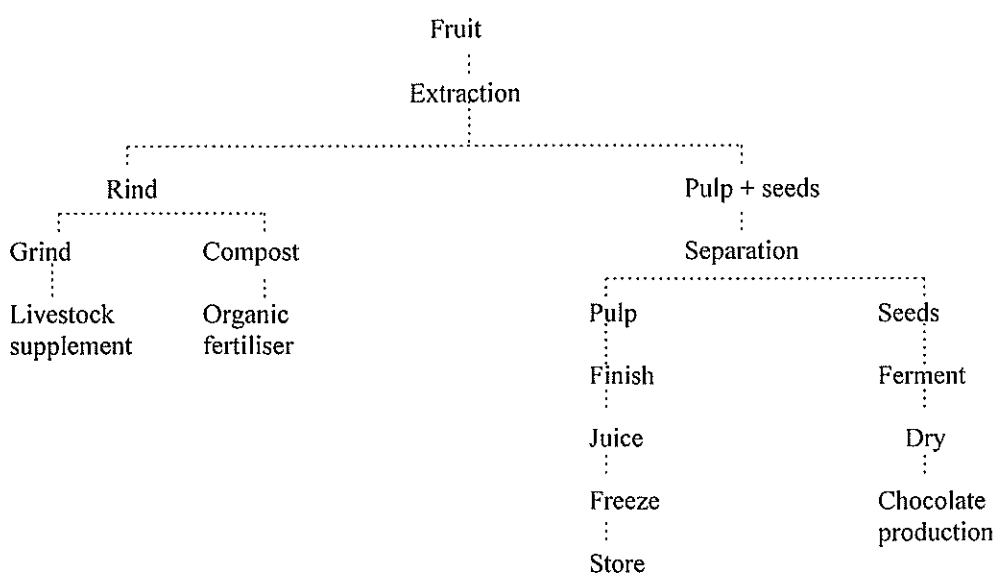


Figure 30. Products of Cupuacu as per Calzavara *et al.* (1984, as cited by Velho, *et al.* 1988).

1.2.7.1.1 Pulp

The pulp (white-yellowish, thick, fleshy and fibrous and aromatic) has been studied as the primary material for fruit nectar, although it can also be used in icecream, jellies, puree and canned pulp (Clement and Venturieri, 1990). Clement and Venturieri (1990) report on the extensive studies undertaken on nectar production. Clement and Venturieri (1990) tabulate the work of others to show the approximate composition of cupuacu pulp (Table 21).

Table 21. Proximate composition of Cupuassu pulp (Clement and Venturieri, 1990).

Reference	% Fresh weight					
	Water	Proteins	Fats	Carbo- hydrates	Fibre	Ash
Chaar (1980)	86.8	1.9	0.5	9.9	1.8	0.7
IBGE (1977)	81.3	1.7	1.6	14.7	0.5	0.7

Pulp extraction is performed manually or mechanically. Mechanical depulping machines have been developed which can process up to 2,500 kg of fruit per hour (Laker and Trevisan, 1992). Calzavara *et al.* (1984, cited by Clement and Venturieri, 1990) presents over 60 recipes for using cupuacu in drinks, pastries, sweets, desserts. Clement and Venturieri (1990) report that those which they have tasted have been excellent.

1.2.7.1.2 Beans

The beans are separated from the pulp, fermented, dried and roasted, thus providing the raw product used to make Cupuacu chocolate, known as Cupulate. Cupulate powder is obtained from the cake left after pressing the beans. The fatty acid composition as a percent of total fats in Cupuacu and Cocoa has been compiled by Velho, *et al.* (1988) and is shown in Table 22. Velho, *et al.* (1988) report that on the basis of the high linoleic content, the seed "butter" of Cupuacu would be expected to have a lower melting point than Cocoa butter. The use of cupuacu seeds for chocolate manufacture is restricted to certain areas in the Amazon.

Table 22. Fatty acid composition as a percent of total fats in Cupuacu and Cocoa (Velho, *et al.* 1988).

Fatty acid	Fatty acid composition (% of lipids)	
	Cupuacu	Cocoa
Palmitic (C16:0)	5.8	32.8
Stearic 9C18:0)	38.3	35.5
Oleic (C20:0)	42.8	29.6
Aracadic (C20:0)	4.8	1.0
Linoleic (C18:3)	8.3	1.1
Total Lipid	58.0	57.3

The literature is scarce on material pertaining to the quality of Cupulate chocolate products. Laker and Trevisan (1992) refer to a pilot trial conducted in Brazil in which

Cupulate in powder and tablet form was found to closely resemble chocolate in colour, smell, taste, consistency and consumer acceptability while Venturieri and Aguiar (1988, as cited by Clement and Venturieri, 1990) report on the composition of home made cupulate.

1.2.7.2 Economic Potential

The economic importance of Cocoa is well known. World production in 1986 was 1.9 million tonnes (Williamson, 1989). Whether cupuacu has the same ability to become a economic crop of world importance is yet to be seen. Numerous references report to its economic importance in Brazil where the fruit and processed products are commonly sold in road side stalls, ice cream parlours, supermarkets and restaurants where US\$3-4 is paid to growers for a kilogram of pulp (Laker and Trevisan, 1992). The value of Cupuacu as a chocolate alternative is yet to be determined.

1.3 Materials and Methods

In 1991, 706 Cupuacu seeds were imported into Australia from Brazil. The consignment was made up of five lots of seed collected from different areas. These were labelled B1 to B5. Seedling establishment rates were low. In April 1992, 130 established seedlings (12 months of age) were planted in the field at Coastal Plains Research Station (Horticulture Block, 12° 35' S, 131° 19' E), 50 km SE of Darwin, NT, Australia.

1.3.1 Planting Pattern

Five rows consisting of approximately 30 plants per row were planted at 3.5 x 3.5 m in a triangular pattern with shade trees (*Gliricidia sepium*) bordering the outside rows and interplanted with the centre row of Cupuacu (Figure 31). At planting, trees were supplied with artificial shade in the form of cylindrical wire frames covered in 50% shade cloth (sides and top). At approximately six months after planting the top shade was removed. Twelve months following planting the artificial shade was progressively removed from vigorously growing plants. At that stage the natural shade was well established. The natural shade was progressively removed from 24 months following planting, with all shade removed by 30 months after planting.

1.3.2 Irrigation

At planting, trees were supplied with a single undertree sprinkler (Wingfield Orbitor[®], flowrate of 70 l/hr, radius of 2.0 m) and irrigation was applied daily except during the wet season for the first 12 months. From 12 months on irrigation was applied three times per week. During 1994 soil water status was monitored at three sites in the block using tensiometers at three depths (20, 40 and 80cm) and neutron moisture meter access tubes.

1.3.3 Fertiliser management

At planting trees were supplied with 30 g of single superphosphate (elemental analysis, P 9.0%, S 10%, Ca 20%). Cupuacu trees receive a basal NPK application once a month, a foliar spray once a fortnight, and an application of Dolomite every 6 months as per Table 23.

1.3.4 Measurements

Monthly measurements of tree growth included tree height (to top of natural foliage height), tree phenology rating (leaf flushing, flowering and fruit set) and incidences of insect and disease were noted. In the last year, yield recording was carried out. Measurements took place from 17 August 1993 (four months after planting) until 27 October 1995.

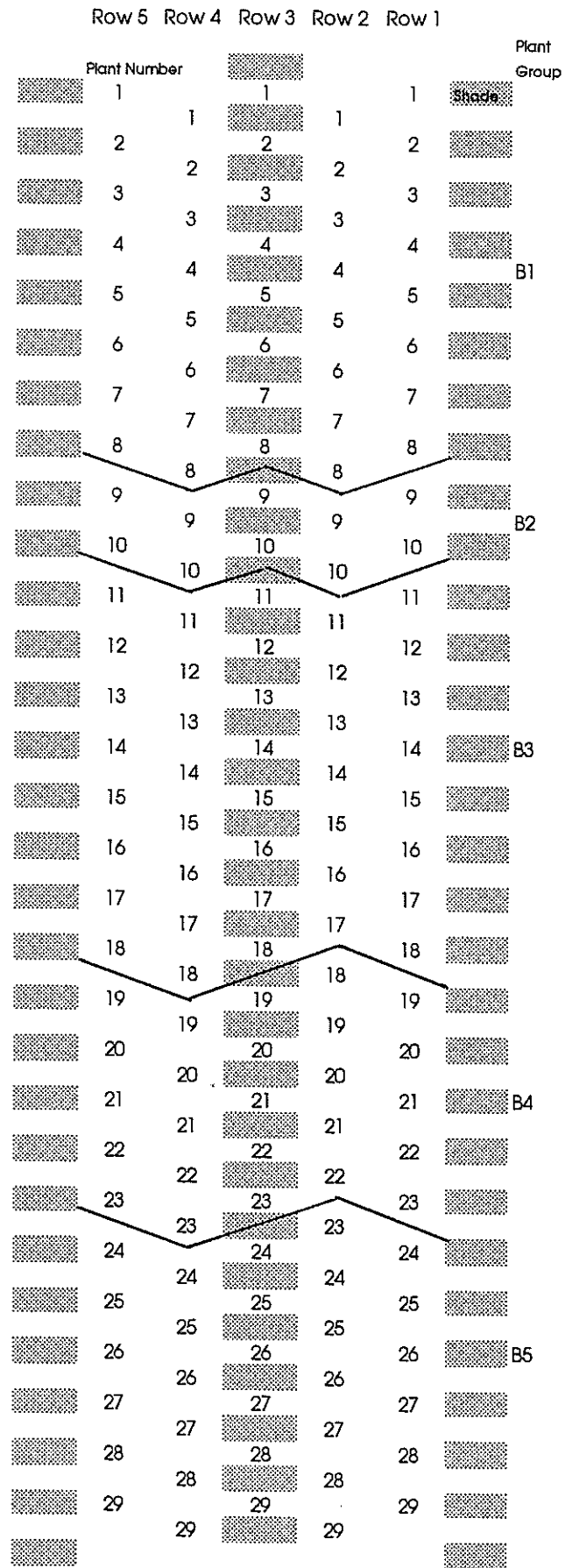


Figure 31. Planting pattern for Cupuacu and shade trees (*Gliricidia sepium*) at CPRS.

Table 23 Fertiliser rates for Cupuacu at CPRS.

Mode	Fertiliser	Rate
Basal	NPK 12:12:17 + TE	70g/tree/month
	Dolomite	90g/tree/ 6 monthly
Foliar	Fe SO4	2g/l Sprayed as
	Zn SO4	2g/l one application
	Mn SO4	1g/l fortnightly
	Boron [#]	1g/l Sprayed fortnightly

[#]Boron sprayed on separately.

1.3.5 Climate

A weather station 2.0 km from the site was utilised for the recording of temperature, rainfall, and humidity.

1.4 Results and Discussion

1.4.1 Climate

In the NT the crop is being grown in a dry tropical climate with a four month wet season and a distinct eight month dry season. The average climatic conditions in the area in which the crop is grown are shown in Table 24. Irrigation is mandatory during the dry season and good crop growth has occurred under high irrigation inputs. The water requirements of the crop has not been studied, however, they are thought to be similar to other crops which have evolved in a wet tropical environment.

Table 24. Average climatic conditions at CPRS (B.O.M. 1992)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)	329	283	272	81	20	2	1	3	13	55	122	197	1378
Max Temp (°C)	32.5	31.9	32.1	33.1	32.3	31.1	30.9	33.0	34.6	35.5	35.2	33.9	33.0
Min Temp (°C)	23.9	23.9	23.7	22.2	19.6	16.4	14.8	17.6	20.3	22.8	23.8	24.0	21.1
R.H. % (0900)	83	87	84	77	70	65	61	68	66	68	73	79	73
Evaporation (mm)*	200	170	185	215	225	210	225	235	245	260	245	230	2645
Radiation (MJ m ⁻² day ⁻¹)*	19.9	20.1	19.9	22.3	20.6	19.8	20.7	22.2	23.6	24.8	24.1	22.6	21.7

* Evaporation and radiation data is from the Darwin Meteorological Station (approximately 50 km to the NW of CPRS).

Weekly average temperature, humidity, rainfall and evaporation data recorded at CPRS during the crop monitoring period are presented in Figure 32 and full page versions are available in Appendix A. The data clearly shows the seasonal fluctuations which occur between the wet and dry seasons. Besides the obvious differences which occur in rainfall the dryseason is characterised by low night temperatures and lower relative humidity (@ 0900 h). In the dry season the night temperatures fall to 10°C. Diurnal temperature recording shows that the low temperatures are only experienced for a short duration just prior to dawn with temperatures rapidly returning to the mid twenties shortly after sun rise (Diczbalis, unpublished data). The dry seasons in 1992 and 1994 experienced significantly lower temperatures than in 1993. Morning RH falls to about 60 % in the dry season from a wet season average of above 80 %.

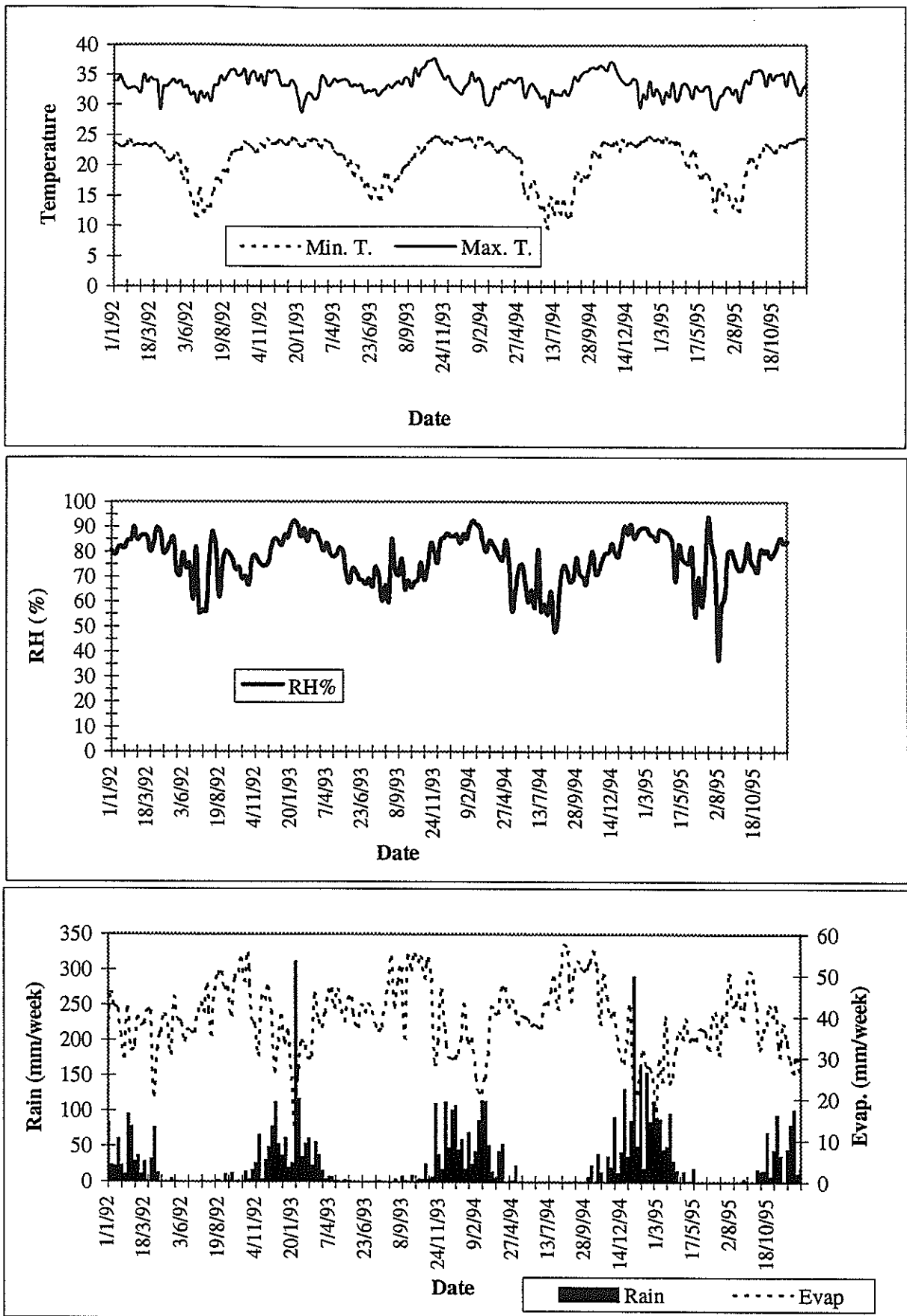


Figure 32. Weekly average max. and min. temperature, humidity, rainfall and evaporation recorded at CPRS during the Cupuacu monitoring period. The rainfall and minimum temperature experienced by the crop in the NT are much harsher than those experienced in it's native environment.

The rainfall and minimum temperature experienced by the crop in the NT are much harsher than those experienced in its native environment.

Maximum temperatures remain fairly constant (32-35°C) throughout the year with the occasional low temperature (25°C) experienced during monsoonal periods in the wet season.

1.4.2 Plant height

Plant height measurements commenced from November 1992, seven months after planting, and was conducted on a monthly basis until October 1995. Data (Figure 33) is presented as a mean of plant grouping (B1-B5) and as means of plant rows (R1-R5).

Over the three year monitoring period plant height increased from a mean of 75 cm to 200 cm. There was no difference in plant height between the various plant groupings. The mean plant height per row shows that final plant height and rate of increase in height was lowest for plants in row 3. There was no differences between rows 1,2, 4 and 5. The position of the rows relative to shade trees was the principle reason for growth differences between row 3 and the others. Row 3 was planted in the same row as the central shade row whereas rows 1,2, 4 and 5 were planted between rows of shade and hence more exposed to full sunlight. The difference in plant height between rows only occurred shortly after the removal of artificial shade from April-June 1993. This indicates that the plants reacted favourably to full light from 12 months after planting.

Slight depressions in plant height which occurred throughout the monitoring period were due to minor pruning activities or the accidental loss of branches while shade trees were being pruned and removed.

1.4.3 Vegetative activity

Flushing activity was initially rated on a 1 to 5 scale. This format was found inadequate to fully describe the nature of vegetative flushing and the level of activity throughout the year. An alternative rating method was chosen whereby each tree was examined and the vegetative flushing rated as a percentage of the total tree activity. For the purposes of this rating method, flushing was defined as shoots with young emerging leaves which were pink in colour. This method of rating was introduced in July 1994 and hence the data shown is for the last 16 months of monitoring.

Flushing activity (Figure 34) is presented as a mean (%) of plant grouping (B1-B5) and as means (%) of plant rows (R1-R5). Trees of all groupings and in all rows had some level of flushing throughout the year with activity levels ranging from 3 % to 30 %. Peak flushing (50-80%) occurred from August to September. This increase in activity coincides with increasing night temperatures following two months of relatively low temperatures. Flushing activity dropped back to basal rates during the wet season. Flushing occurs approximately every six weeks for each tree, however, flushing is not synchronous between trees hence the data suggests that low level flushing occurs throughout the year

1.4.4 Flowering

Flowering was first noted in November 1992, seven months after planting, with approximately 50% of trees experiencing some level of flowering by August 1993. Flowering activity (% of tree), from December 1993 to October 1995, is presented as a mean of plant grouping (B1-B5) and as means of plant rows (R1-R5) (Figure 35).

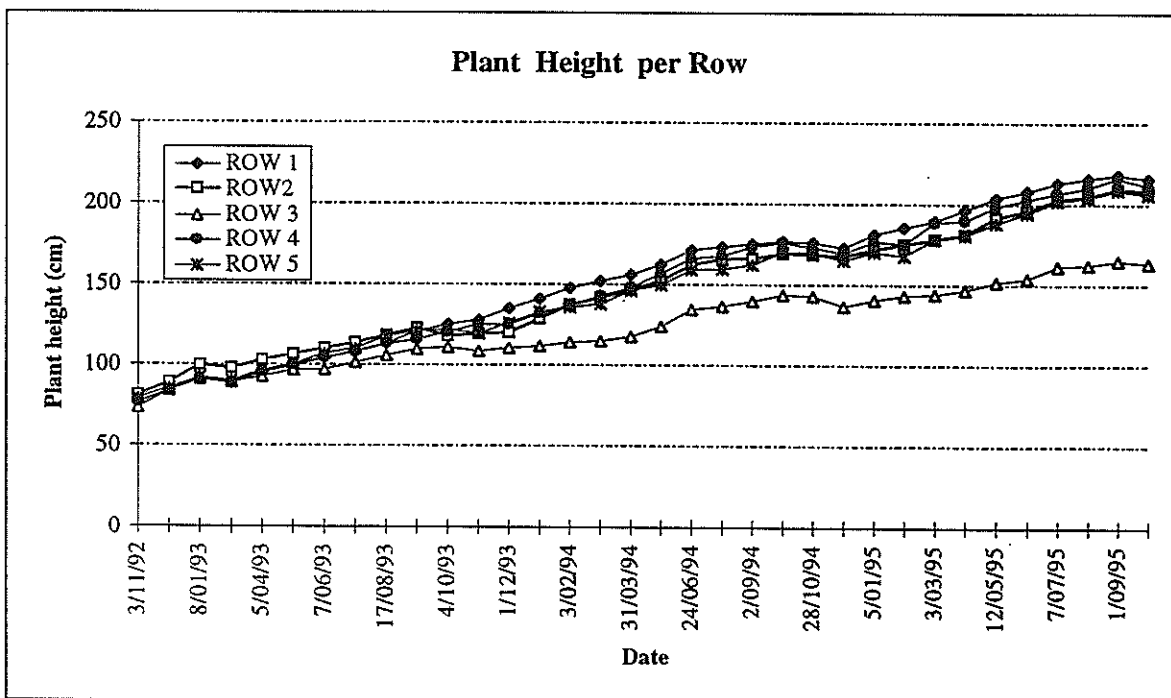
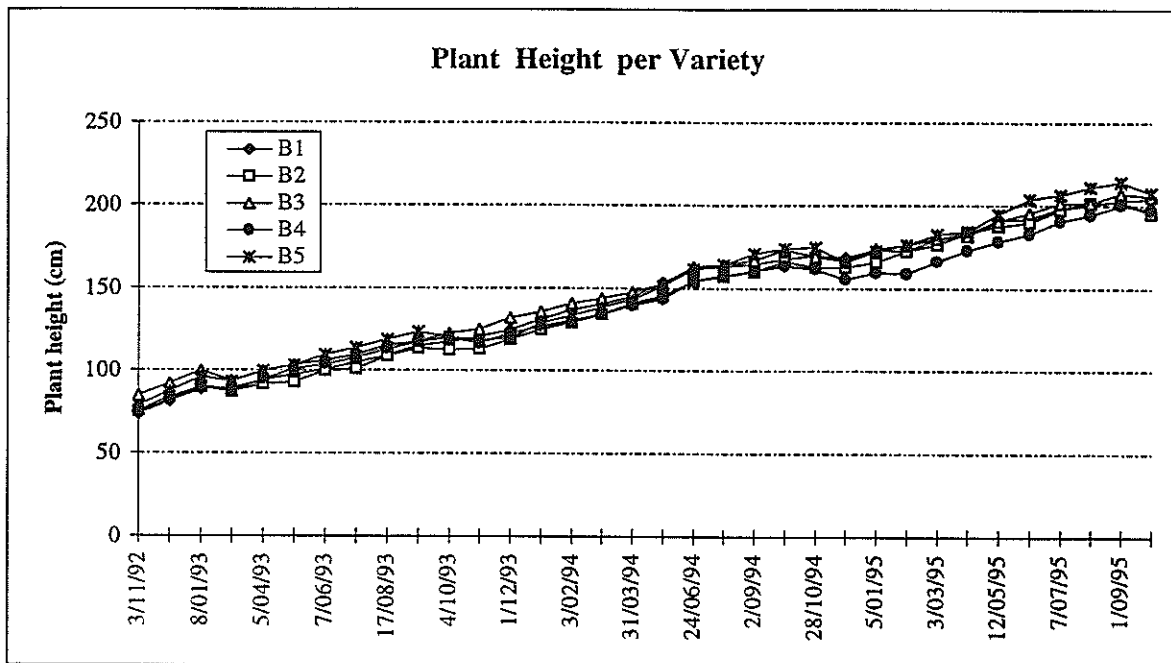


Figure 33. Plant height measurements as a mean of plant grouping (B1-B5) and as a mean of plant rows. (R1-R5).

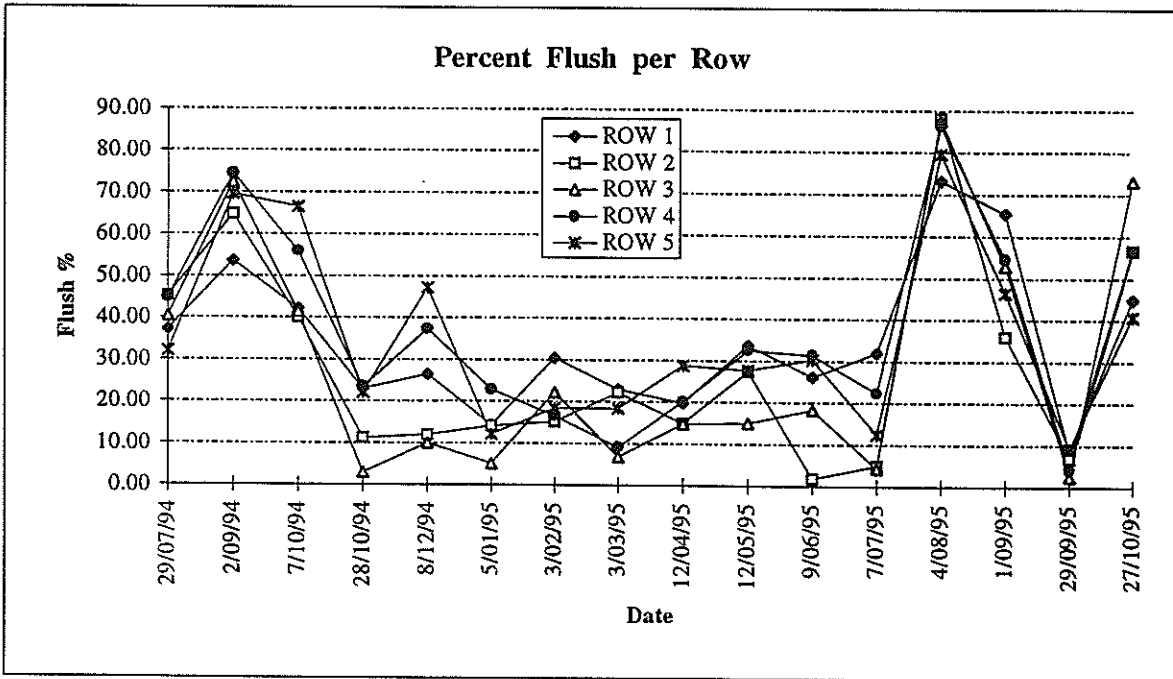
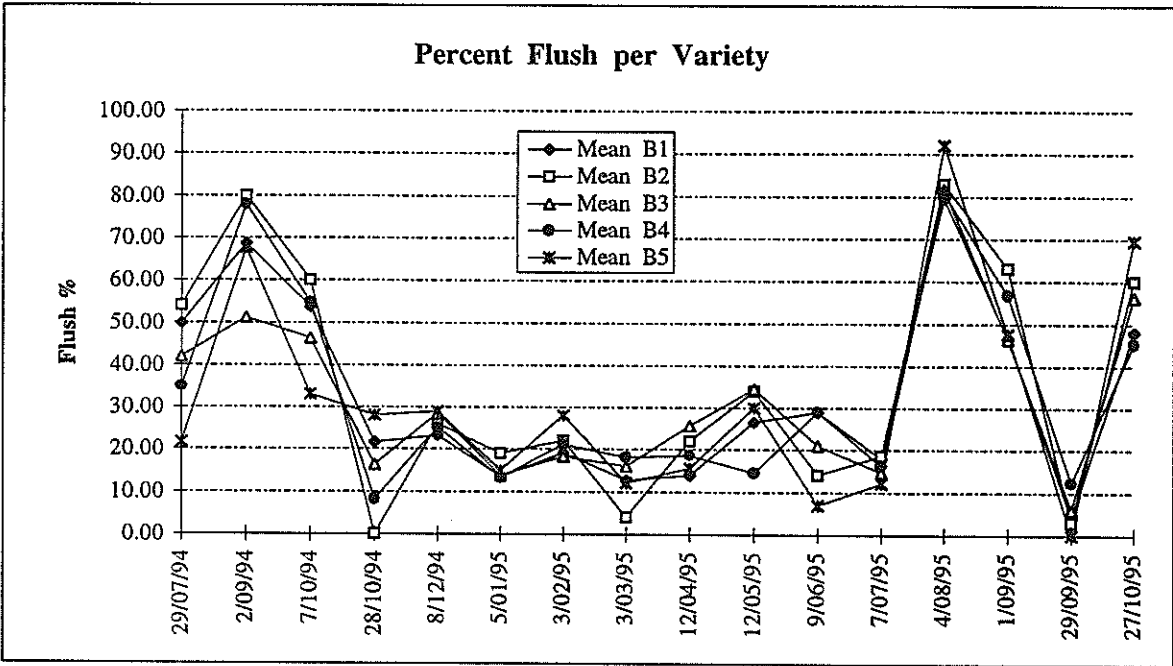


Figure 34. Percent flushing activity as a mean of plant grouping (B1-B5) and plant rows (R1-R5).

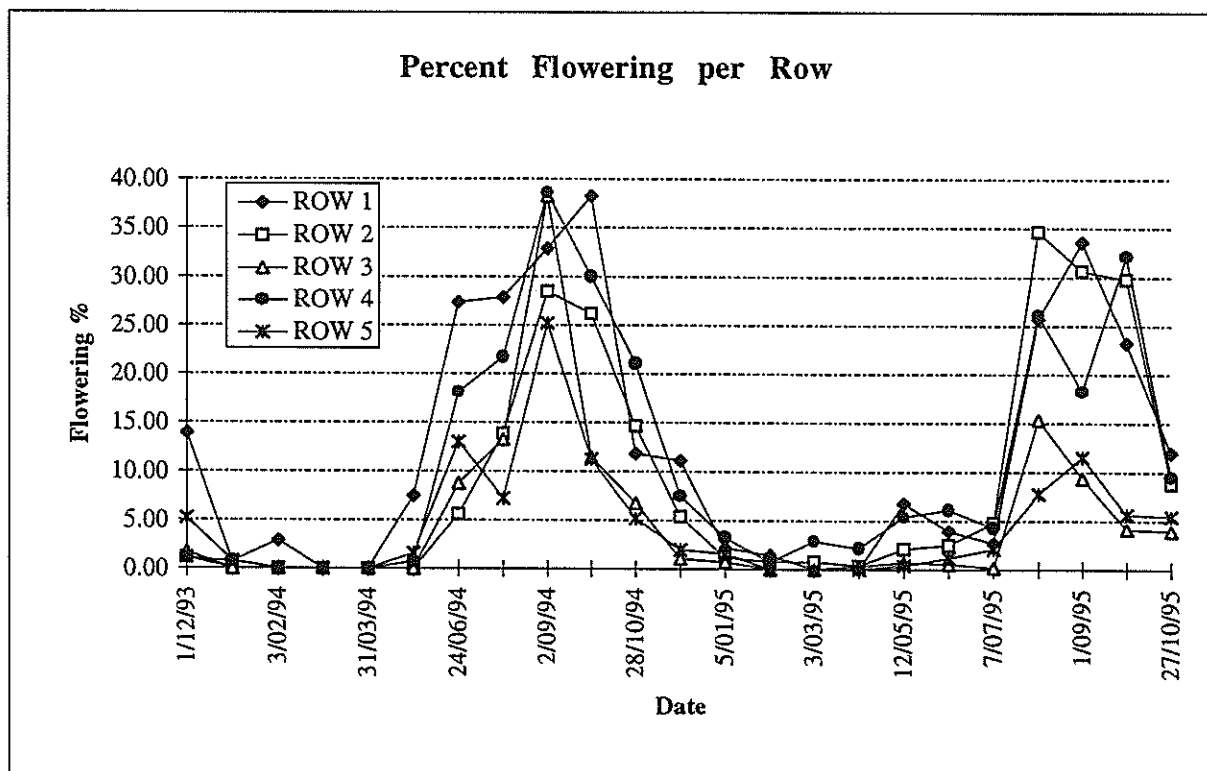
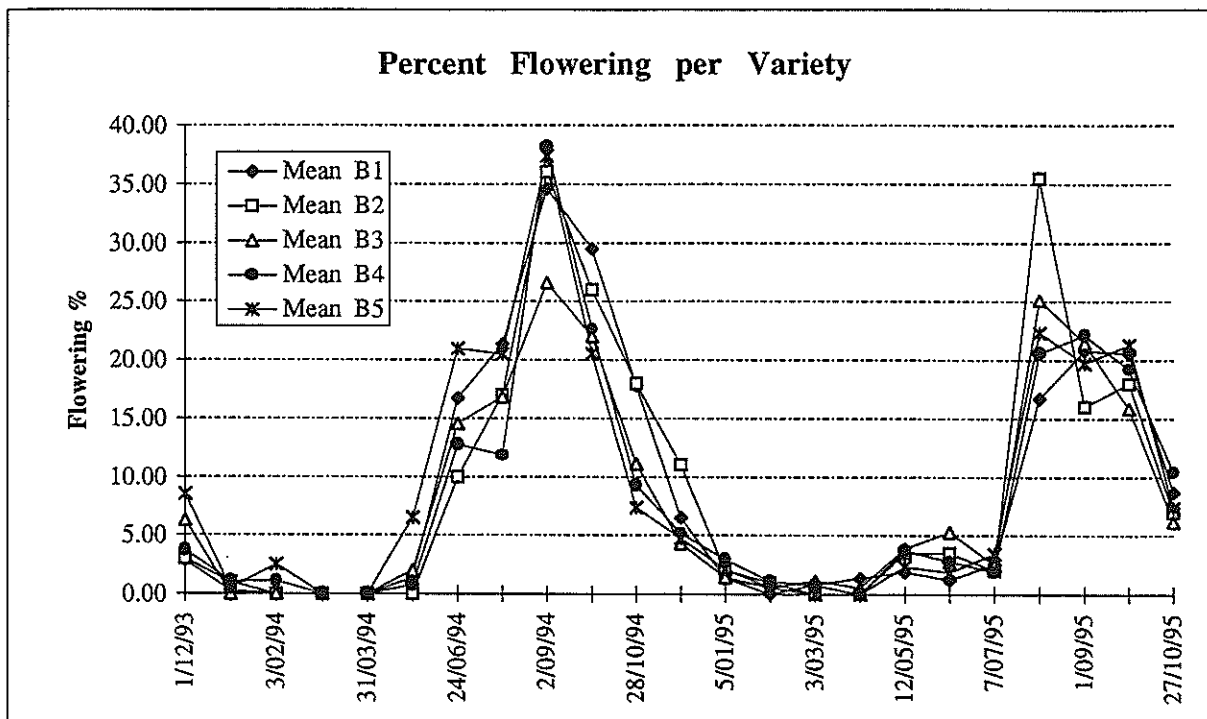


Figure 35. Flowering data (mean % flowering activity) per plant grouping (B1-B5) or plant rows (R1-R5).

The mean values include non-flowering trees and hence does not record the fact that some trees within the plant grouping or row may have been experiencing 100 % flowering. The data is extremely useful for indicating the level of flowering activity throughout the year. The figures clearly show that flowering activity occurs from July through to October with a peak in activity occurring from August to September. There was no difference in flowering activity between groups of plants. The variation which occurs between rows of plants was more noticeable however given the large variation which occurred within the row these differences could not be considered as significant. The trends in activity were similar which indicates that plants were responding to the environment in a similar way.

1.4.5 Fruiting

The period during which fruitset and fruit development occurred was monitored from the time of first fruitset (November 1993) until October 1995. Data on numbers of trees fruiting per row and percentage fruiting per variety are shown in Figure 36. The data shows that there was a distinct period in which fruit were setting and filling (September to May) with little to no fruiting occurring during the remainder of the year. Fruit set in row 3 (shaded row) was less than that experienced in the remaining four rows, particularly after the initial set. This indicates that trees in this row had less capacity to maintain fruit through to maturity.

During the peak fruitset period only a quarter to half the trees in each row recorded fruitset. At three years of age, since planting, the trees appeared to be exiting the juvenile phase. The recording did not include fruit number per tree or final fruit set. This data is planned to be recorded once trees are mature and full flowering and fruitset are taking place.

Tree grouping did not appear to affect the fruiting pattern, although there was an unusual difference recorded in June 1994, when 20 % of trees were fruiting in the B5 group whereas it ranged from 0 to 5 % for trees from the other four selection groups.

1.4.6 Pod characteristics and small scale recovery

A small sample of pods (8) harvested in June 1994 were investigated for pod weight, length, pulp plus seed weight and seed number (Table 25). The mean pod length was 144.3 mm with a range of 108.0 to 186.6 mm. Mean pod weight was 656.5 g ranging from 418.0 to 1057.1 g. The mean seed number per pod was 21 ranging from 6 to 30.

Following the weight and seed count measurements the samples were bulked and the pulp was removed from the seed and the wet seed weight measured. Seed were dried in an oven at 65°C for two days and recovery weights calculated as per Wood (1985b) (Table 26). Recovery rates were 51.7 %, 31.5 % and 12.4 % for pulp + seed, seed fresh weight and seed dry weight respectively.

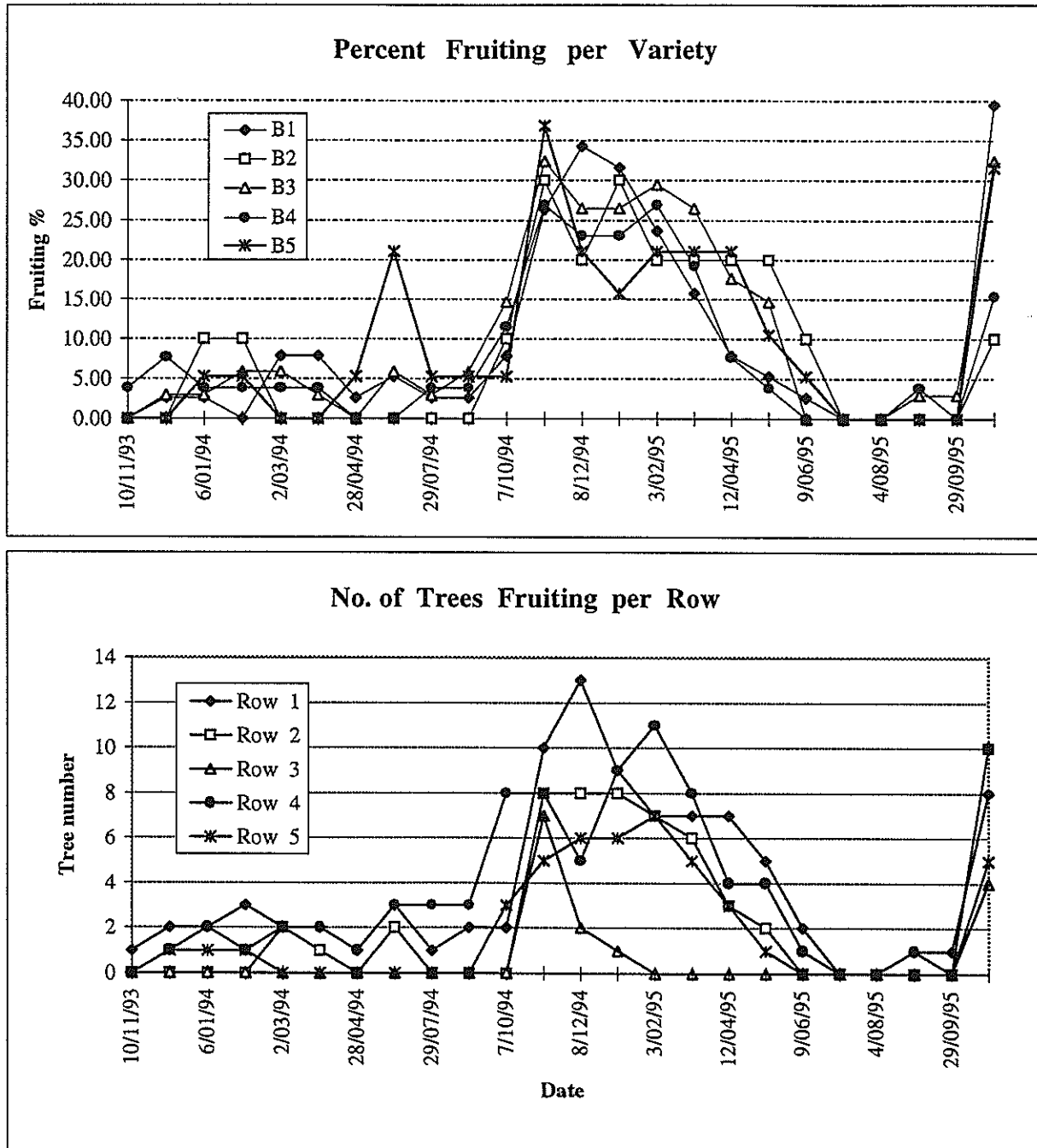


Figure 36. The percentage fruiting per plant group (B1-B5) and number of trees fruiting per row.

Table 25. Pod length, weight, pulp and seed weight, and seed number of Cupuacu.

Row number	/tree	Pod length (mm)	Pod weight (g)	Pulp + seed weight (g)	Seed number
1-14-B3		156.5	789.5	396.6	29
4-15-B3		186.6	1057.1	514.3	30
1-12-B3		173.7	968.6	516.7	27
4-6-B1		125.1	441.0	257.6	21
1-14-B3		148.8	742.0	404.6	27
1-14-B3		141.1	444.0	202.6	6
1-14-B3		108.0	383.0	204.7	16
5-12-B3		114.4	418.0	220.2	10
Total			5252.2	2717.34	
Mean		144.3	656.5	339.7	20.8

Table 26. Small sample recovery data for Cupuacu.

Total Pod number (8)	Weight (g)	Recovery %
Total pod	5252.2	
Total seed + pulp	2717.3	51.7
Wet beans	854.61	31.5
Dry beans	338.1	12.4

1.4.7 Tree yield

Early estimates of tree yield were carried out following a single harvest from all trees in early April 1996 (Table 27). Mature tree-borne fruit and freshly fallen fruit were harvested, labelled, counted and weighed. Fruit which were immature were not harvested and subsequent visual estimates were made.

Mean pod size was 451 g with a range from 150 g to 1439 g. The pod number per tree ranged from zero to 25 with the average pod number per tree of 5.8. The analysis of the data does not allow any quantitative discussion on the productivity of the different plant groupings. Average number of pods per tree for the five plant groups ranged from 3.84 to 6.72 for plant groups 1 and 3 respectively.

Table 27. Cupuacu harvest data (single harvest) for four year old trees at Coastal Plains Research Station.

Plant group	Total number of trees	Pod count	Av. No. of pods/tree	Av. pod weight (g)	Average yield/tree (kg)	Total yield (kg)
1	38	146	3.8	307.5	1.96	74.45
2	10	65	6.5	472.8	3.80	38.05
3	39	262	6.7	574.4	4.10	459.92
4	21	128	6.1	476.3	3.24	68.03
5	20	112	5.6	423.9	2.82	56.33
Total	128	713				396.77

Total weight of pods harvested was 396.8 kg. At a density of 816 plants per hectare this is equivalent to a yield of 2,530 kg/hectare. Yield from fruit maturing over the subsequent two months is thought to be equal to that removed in early April. Hence realistic early estimates of yield for four year old Cupuacu trees in northern Australia is 5,000 kg/ha.

1.4.8 Dry bean recovery (bulk sample)

Following the acquisition of yield data from the April 1996 harvest, 89 pods, free of external or internal fungal infection, were selected for trial fermentation and calculation of dry bean recovery. Pods were broken and the pulp and seed scooped out and placed in a styrofoam insulated fruit crate. Banana leaves were added to the top of the pulp, for wild yeast inoculation, and the seed mass was covered with a styrofoam lid. The mass was stirred on a daily basis and temperature monitored. Fermentation did not take place and no increase in ambient temperature was noted. The pulp temperature remained at 28-30°C for 10 days. Although fermentation did not take place the pulp degraded due to fungal and insect infestation(soldier fly larvae; Fam. Stratiomyidae). Following the trial 10 day fermentation period the remaining seed and pulp was washed and pulp removed. The seed was sun dried for one day and then dried in a commercial plant dehydrator at 60°C for two days. Pod weight, and recovery data is shown in Table 28.

Table 28. Dry bean recovery data.

	Weight (kg)	% Recovery
Total pod weight	40.14	-
Fresh seed + pulp (fresh wt./total pod wt.)	33.0	82.2
Dry seed	3.4	-
Recovery (dry seed wt./fresh pulp + seed wt)	-	10.3
Recovery (dry seed wt./total pod wt)	-	8.5

The dry bean recovery (wt. dried fermented beans/wt of unfermented beans) is 10.3 % as calculated by the method described by Wood (1985b). This does not compare favourably with cocoa recovery rates which range from 31.5 to 46 % as reported by Rohan, (1963, as cited by Wood 1985b). The large differences in recovery rates between cocoa and cupuacu is due to the large mass of pulp attached to the seeds of cupuacu whereas cocoa seeds are covered in a thin musilagenous layer.

Calculation of dry bean yield based on the above fermentation exercise is 214 kg/ha. Given that fresh pod yield estimates are thought to be double that harvested the potential dry bean yield is nearer to 430 kg/ha. This yield compares poorly with the best production from cocoa plantations of a similar age (Wood, 1985a) where yields of dry beans are reported as high as 1,400 kg/ha.

1.4.9 Pests and diseases

During the crop growth monitoring period a record of pests and diseases observed was collated. Most pests observed were not serious, however, in a number of cases control measures had to be carried out. Table 29 lists the pests and diseases and the level of severity and the ease of control.

The most serious pest was fluted scale (*Icerya* sp.) commonly called mealybug which congregated in the growing tips causing malformation in the newly emerging leaves. The incidence of fluted scale declined once the shade trees (*Gliricidia sepium*) were removed, suggesting that the shade trees were also a major host, or that they hosted mealybug attending species as has been reported to occur in cocoa (Entwistle, 1985). The other major pest encountered was *Monolepta australis* (swarming beetle) which when in swarms rapidly defoliated plants. Control was relatively easy. Another major swarming species was *Graptostethus servus*, which congregated on the trees in large numbers, during the early part of the dry season, but did not appear to cause any damage. Minor foliage damage was caused by a range of caterpillars from the order Lepidoptera. There were no recorded pests of pods while the pod was still attached to the tree, although some pod drop shortly after fruit setting may have been caused by fruit sucking bugs such as *Helopeltis pernicialis*. Pod borers and scolytid, were found on fallen pods which in most cases had been on the ground longer than a week. Another beetle (not identified) was responsible for boring a hole through the peduncle scar of fallen fruit and caused minor damage to pulp at the peduncle end of the fruit. This allowed access to pathogens such as *Botryodiplodia theobromae*.

There were no major plant or pod diseases recorded. *Phomopsis* sp. was found associated with a minor incidence of branch dieback and was most likely secondary in nature. The pod fungus *Botryodiplodia theobromae* was found on and in pods which had dropped and that had spent a week or more on the ground or had been damaged during the fall.

1.4.10 Irrigation monitoring

In 1994 soil moisture, within the canopy area, was monitored weekly using both tensiometers and neutron moisture probe (NMP). A water meter was installed in late July to monitor irrigation inputs for the remainder of the year. NMP, soil tension, water inputs (mm/wk) and irrigation input data is shown in Figure 37. The irrigation regime, controlled manually, using 70 l/h micro sprinklers was four hours three times per week (Monday, Wednesday and Friday). The total weekly inputs should have been approximately 840 litres per tree per week. During the wet season irrigation was applied if less than 40 mm per week had fallen. The data suggests that soil moisture levels were maintained at a high level through out the year due to either rainfall or irrigation inputs. Data on irrigation inputs is missing for the first seven months of the year, however, given the irrigation regime, as detailed above, the inputs would have been similar to those monitored from the end of July. The irrigation input data clearly shows the variability that occurs with manually controlled irrigation systems. However, the most important feature of this data is that irrigation inputs were in excess of plant water requirements. The soil tension data shows that tensions rarely exceeded 0.16 MPa at any of the three depth (20, 40 and 80 cm) monitored. For the bulk of the monitoring period, soil tension at 20 cm ranged from 0.05 to 0.1 MPa indicating that the shallow soil horizons were maintained at saturation to field capacity.

Although not formally tested, water requirements of Cupuacu are probably not that dissimilar to tropical fruit species such as rambutan. Work conducted in the Northern Territory suggests that the crop factor for rambutan ranges from 0.65 to 1.21 (Diczbalis et al. 1996).

Table 29. List of Cupuacu pests and diseases, and their severity noted, on trees grown at Coastal Plains Research Station.

Scientific Name	Common Name	Damage	Severity Rating	Ease of control
Insect Pests				
<i>Monolepta australis</i>	redshouldered leaf beetle	young shoot defoliation	high	easy
<i>Graptostethus servus</i>	swarming bug	no damage	low	easy
	tussock moth	defoliation	low	easy
Lymantriidae	caterpillar			
	beetle	defoliation	low	easy
Flatidae	plant hopper	sap feeder	low	easy
	aphid	sap feeder	medium	easy
<i>Toxoptera</i> sp.	false spider mites	sap feeder	low	medium
Tenuipalpidae	bark beetle	pod borer	medium on fallen pods	not attempted
Curculionidae				
subfam.				
Scolytinae				
<i>Achaea janata</i>	castor oil looper	defoliation	low	easy
Noctuidae	caterpillar	defoliation	low	easy
Labiduridae	earwig	enters cracked fruit	low	not attempted
	fluted scales	sap feeder	high	difficult
<i>Icera</i> sp.	leaf roller	leaf curl/defoliation	low	medium
Tortricidae	soldier fly larvae	infest fermenting beans	medium	not attempted
Stratiomyidae				
Diseases				
<i>Phomopsis</i> sp.	die back	associated with dieback	branch low	not attempted
<i>Botryodiplodia theobromae</i>	botryodiplodia	pod rot	medium on fallen pods	not attempted

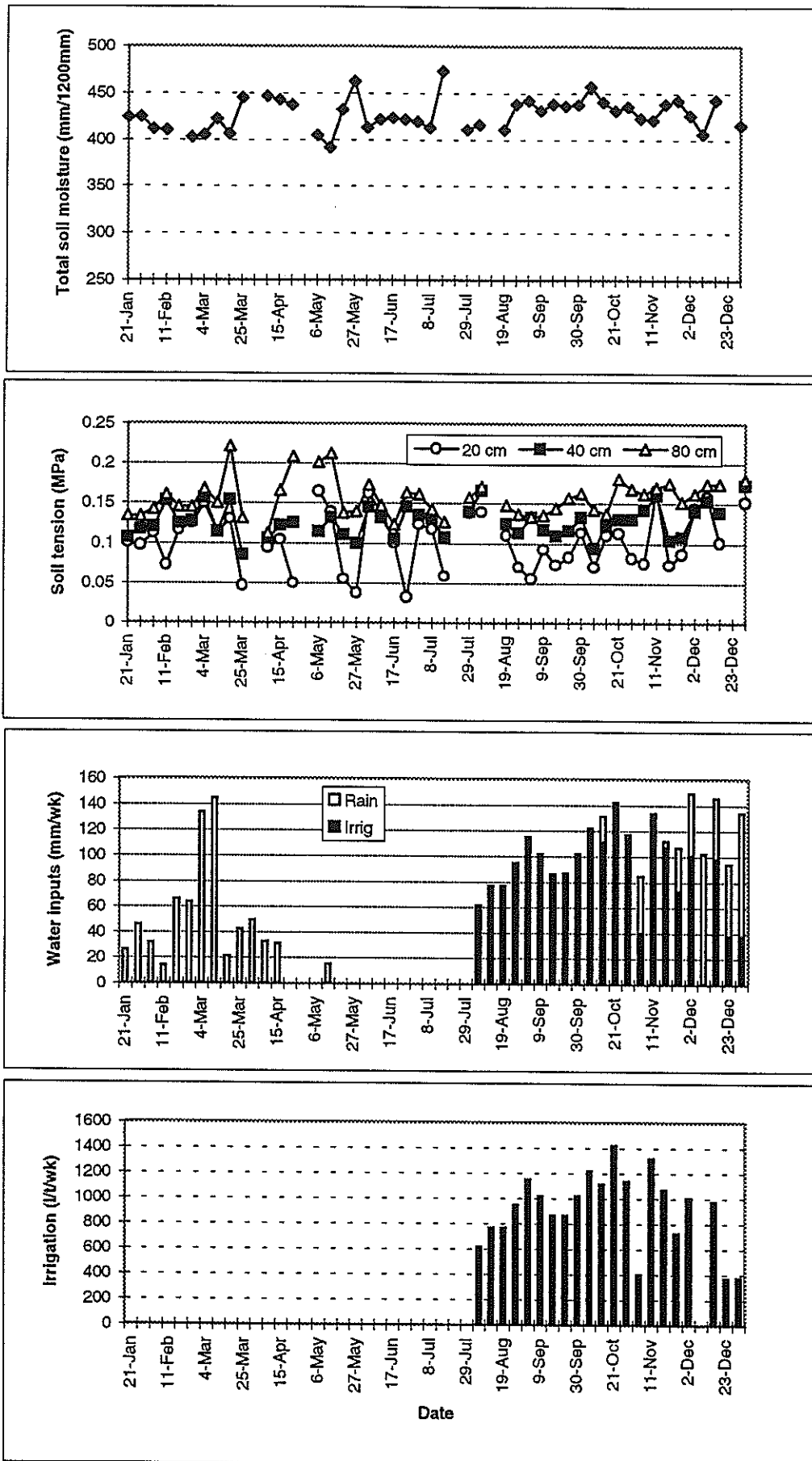


Figure 37. Weekly soil moisture and tension data and irrigation and rainfall inputs for Cupuacu grown at CPRS during 1994. Note; irrigation input recording commenced in August 1994.

1.5 Summary

Cupuacu established and grew well in the wet dry tropics of northern Australia. It is difficult to compare its performance directly with that in its native environment as there is a paucity of information in this area. No work has been conducted to ascertain the water requirements of cupuacu and whether irrigation management could be used to manipulate crop growth (flowering, fruit numbers and size). Despite the lack of water requirement information there is little doubt that the crop would not thrive during the long dry season experienced in the NT without supplementary irrigation.

The estimated pod yield of four year old trees was 5,000 kg/ha at a planting density of 816 plants/ha. This translates to a dry bean yield of approximately 430 kg/ha. Although this is expected to increase with time it is a low yield compared to Cocoa where dry bean yields of similar aged trees are reported as high as 1,400 kg/ha. The main disadvantage with Cupuacu is its relatively low recovery rates (10%) compared to 31.5-46% for Cocoa. Hence to achieve similar dry bean yield the production of fresh pods has to be much higher. The direct comparison of Cupuacu and Cocoa yield data may not be appropriate in the NT due to the slower growth rates observed in Cupuacu. Although no direct measurements have been made, observations indicate that Cocoa growth rates are appreciably higher than Cupuacu under growing conditions experienced in the NT.

The products of Cupuacu, pulp and dry roasted beans, need to be examined for their commercial acceptability. Although these products are used in the country of the crops origin the commercial acceptability and economic feasibility of the products needs to be closely examined. To date there is no available data on the commercial acceptability of the dry roasted product as a chocolate alternative. Considerably more information is available on the use of the pulp in the manufacture of fruit nectar.

The consultants report on the feasibility of a Cupuacu industry in Australia (Duncan and Ascenso, 1990) suggests that the value of Cupuacu as a chocolate alternative will be due to the following features;

- its relatively high butter fat content (64 %)
- the low level of stimulants; caffeine and theobromine
- superior bloom inhibiting qualities. (Bloom is the expression used to describe when chocolate turns white during storage).

Cupuacu's use as a chocolate alternative needs to be thoroughly evaluated prior to further agronomic studies being undertaken. The plot at CPRS will now produce sufficient yield for trial fermentation and evaluation of roasted product to occur. Ideally this work should be done in conjunction with a confectionery manufacturer. Evaluation of the pulp as a flavouring in nectars and juices would increase the economic viability of the crop if it is found to be commercially acceptable.

Should either or both the products of Cupuacu be found to be commercially acceptable and economically viable, the fact that the pods drop to the ground when mature greatly assists the commercialisation of the crop in a mechanised agricultural system as exists in Australia. Mechanical harvesting would be the preferred option, however, frequent passes of the orchard would be required so as to ensure that spoiling of the pods through insect or pathogen attack did not occur.

The work reported in this study is only the second stage of the potential commercialisation process of the crop. The evaluation of commercial products is the essential next step in the commercialisation process.

1.6 Acknowledgments

We would like to thank Nick Richards, Paul Albano, Paul Watson, Marion Chisholm for their technical and physical input into the project. The physical input of CPRS staff who assisted in the day to day maintenance of the crop is also gratefully acknowledged. We also thank staff of the entomology and pathology units for identifying the pests and diseases present on Cupuacu.

1.7 References

- Bureau of Meteorology, (1988). Climatic averages Australia. Australian Government Publishing Service, Canberra,
- Clement, C.R. and Venturieri, G.A. (1990). Bacuri and Cupuassu *in* Fruits of Tropical and Subtropical Origin ed. S. Nagy, P. E. Shaw and W. F. Wardowski. Florida Science Source , Inc.
- Diczbalis, Y.A., Eamus, D. and Menzel, C.M. (1996). Environmental factors influencing the growth and yield of rambutan grown in the wet/dry tropics of northern Australia. Proceedings of the International Conference on Tropical Fruits; Kuala Lumpur, Malaysia, 23-26 July, Vol 2; 15-24.
- Duncan, I. and Ascenso, A. (1990). A preliminary review of the potential for cupuacu in Australia. Consultants report to the Department of Primary Industry and Fisheries.
- Entwistle, P.F. (1985). Insects and cocoa *in* Cocoa ed G.A.R. Wood and R. A. Lass, Longman Scientific and Technical, Harlow, UK.
- Laker, H.A. and Trevisan, O. (1992). The increasing importance of Cupuassu (*Theobroma grandiflorum*) in the Amazon region of Brazil. Cocoa Growers Bulletin, 45:45-52.
- Velho, C.C., Whipkey, A. and Janick, J. (1988). Cupuassu: A new beverage crop for Brazil *in* Proceedings of the First National Symposium New Crops: Research, Development, Economics. Indianapolis, Indiana, October 23-26, 1988. ed J Janick, and J.E Simon. Timber press, Oregon.
- Williamson, A.P. (1985). Marketing *in* Cocoa ed G.A.R. Wood and R. A. Lass, Longman Scientific and Technical, Harlow, UK.
- Wood, G.A.R. (1985a). Establishment *in* Cocoa ed G.A.R. Wood and R. A. Lass, Longman Scientific and Technical, Harlow, UK.
- Wood, G.A.R. (1985b). From harvest to store *in* Cocoa ed G.A.R. Wood and R. A. Lass, Longman Scientific and Technical, Harlow, UK.