

SOME ECOPHYSIOLOGICAL ASPECTS OF CASHEW
(*Anacardium occidentale* L) WITH EMPHASIS ON POSSIBLE
FLOWER MANIPULATION IN MAPUTALAND

By

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ABSTRACT

There has been interest in developing a cashew industry in Maputaland, the far north-eastern corner of Natal/KwaZulu. Flowering and fruit development coincide with a rainy period, with accompanying serious flower diseases (*Oidium anacardii* and *Colletotrichum gloeosporioides*). Glasshouse studies were carried out at Pietermaritzburg, concurrently with field trials in Maputaland, in an attempt to manipulate flowering and growth of cashew trees.

Two glasshouse trials were carried out. A factorial design with treatments 0, 3, 6 and 9 weeks of low temperatures (24°C day/ 9°C nights) (factor A) and 0, 3, 6 and 9 weeks of water deficit (Factor B) was used, with both factors in all combinations. During the second season the durations were increased to 0, 4, 8 and 12 weeks for both factors. No flowering occurred in this trial. Tree growth was not affected significantly by drought and/or cold duration. Temperature appeared to be the dominant factor at low temperatures, stomatal conductance and transpiration being suppressed by cold regardless of soil water potential. At more optimum temperatures for growth, stomatal conductance was dependent on soil water potential ($r^2 = 0.756$). Starch levels in the roots, dry matter production in the leaves, roots and stems, as well as leaf area were decreased significantly ($P \leq 0.01$) with increasing low temperature duration. Another glasshouse trial to test the effects of foliar urea at concentrations of 0, 1, 2, 4 and 8 g urea 100 l⁻¹ applied once, twice or thrice at fortnightly intervals was undertaken. The treatments were applied in late autumn/ early winter of 1990 and 1991. Tree growth and flowering were monitored, and starch and leaf NH₃/NH₄⁺ analyses carried out. The highest urea concentration (8%) resulted in leaf scorch and abscission, extremely low stem diameter growth rates, and was too high for glasshouse trees. The starch contents of the 8% urea treatment were depleted significantly ($P \leq 0.01$) more than the other concentrations. The other urea treatments resulted in vigorous growth and high dry matter production. There were no significant effects of the number of sprays on cashew growth. Only seven trees flowered, and therefore no definite conclusions could be drawn regarding urea effects on flowering. Most hermaphrodite flowers (max. 76.8% hermaphrodite) opened soon after first anthesis of a panicle, and all terminal flowers of panicle branches were hermaphrodite. Flowers generally opened basipetally in a panicle, starting with hermaphrodite flowers and with progressively more male flowers. Urea sprays resulted in NH₃/NH₄⁺ build-up in the leaves, concentrations in flowering trees ranging from 100 to 700 µg g⁻¹ DM for approximately a month.

A field trial was carried out at Makatini Research Station to determine the effects of timing of a two month winter drought period on flowering and growth. An observational trial to determine the effects of girdling on growth and flowering was incorporated in the border rows of the irrigation trial. The trial tested five treatments (no irrigation during May and June, June and July, July and August, August and September, and a control treatment which received irrigation throughout winter). Mean monthly temperatures were below 20°C, and mean minimum temperatures below 15°C for the 5 winter months during treatment application. There were no significant differences in tree growth, flowering, flushing,

or yields between drought stressed treatments and control, indicating that, under the conditions at Makatini, autumn and winter temperature was the overriding factor controlling initial flower induction. Flowering occurred from early October (when mean temperatures exceeded 23 to 24 °C) to late April (7 months - a prolonged flowering period), when mean monthly temperatures dropped below 23 to 24°C. Girdling of cashew trees in March and May, using girdle widths of 1, 5 and 10 mm was not successful in improving flowering and yields under the conditions of the trial.

A field trial was carried out at Mosi Estate in Maputaland to test the following chemicals as tree and/or flower manipulators: foliar applied ethephon (50, 100, 200, 500, 2000 mg l⁻¹), KNO₃ (1%, 2%, 4%), urea (1%, 2%, 4%) and paclobutrazol (500, 1000, 2000 mg l⁻¹). A phenological model for cashew in Maputaland showed a dormant period during winter, followed by a generative flush, from which panicles and flowers were produced (peak November-January). The harvest period peaked in February and March. A strong post-harvest flush preceded the winter dormant period. Trunk starch levels were at their highest after the dormant winter period, and at their lowest following the harvest. Ethephon at high concentrations (500 and 2000 mg l⁻¹) resulted in excessive leaf drop, disturbed the root:shoot balance and normal phenological patterns, and gave poor yields. The best ethephon concentrations were 100 to 200 mg l⁻¹. KNO₃ had no significant effect on tree growth, flushing, flowering or yields when compared to control trees. Urea at 2% concentration gave a significant increase ($P \leq 0.05$) in flushing and simultaneous decrease in flowering. Paclobutrazol at 500 to 2000 mg l⁻¹ resulted in significantly lower growth rates, and early panicle production. The mean yields of all paclobutrazol treated treatments were higher than controls, despite a hail storm which damaged the flowers. From results of this trial, the use of these chemicals to improve yields and manipulate flowering may not be economically justified. The most promising chemical for further research was paclobutrazol.

DECLARATION

I hereby declare that the research work reported in this thesis is the result of my own investigations, except where acknowledged.

Signed

A handwritten signature in black ink, appearing to read 'D. Roe', written over a horizontal line.

(DENIS JOHN ROE)

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CHAPTER 1: GENERAL INTRODUCTION

Maputaland (Appendix I) covers the area stretching north from Lake St Lucia and is bounded in the east by the Indian Ocean, in the west by the Ubombo Mountains, and in the north by the Mozambique border with Natal/KwaZulu. This area is probably the closest approach in South Africa, apart from parts of the Kruger National Park, to a tropical climate. It forms part of the southernmost portion of one of Africa's largest coastal lowlands, which stretches down the east coast from Somalia in the north. Maputaland forms the juncture between the high altitude inland plateau and the coastal lowlands and therefore includes fauna and flora from the temperate west and the tropical north. This unique location contains one of Africa's most diverse biotas.

There has been an attempt to start a cashew industry in Maputaland, in the Mosi Palmveld. The Mosi palmveld is typified by scattered palms, e.g. wild date (*Phoenix reclinata*) and lala palm (*Hyphaene coriacea*), in a grassland matrix (Bruton, 1980). This area has recently become the focus of attention for agricultural development, especially cashew (*Anacardium occidentale* L.) cultivation (IDC, 1992). As part of a cashew feasibility study, ecophysiology studies were carried out in glasshouses (Pietermaritzburg) and in the field (Maputaland) to determine whether cashew growth and flowering could be manipulated, as the coinciding of the rainy season and flowering was identified as one of the limiting factors for a commercial venture in Maputaland.

A. occidentale belongs to the family Anacardiaceae, which comprises about 60 genera and 400 species of trees and shrubs with resinous bark, and grows most abundantly in the dry monsoonal tropics. Several other important fruit and nuts such as the mango (*Mangifera indica* L.), the pistachio nut (*Pistacia vera* L.) and various species of *Spondias* (mombin, Otaheite apple) belong to this family (Ohler, 1979). Some notoriously poisonous plants such as poison ivy (*Rhus toxicodendron* L.), poison sumac (*R. vernix* L.) marking nut (*Semecarpus anacardium* L.), etc., are also members of the family (Morton, 1961). In South Africa the well known indigenous marula (*Sclerocarya birrea* subsp. *caffra* Sond. (Kokwaro)), karee (*R. lancea* L.) and a host of other trees belong to the family Anacardiaceae (Coates Palgrave, 1988). *A. occidentale* is the only species in the genus which has attained economic importance (Ascenso, 1986a).

The lowland Amazon region is the most probable area of origin of the genus. The local Indians used cashew fruit and pseudo-fruit for centuries before the arrival of the first colonists, and these Indians probably dispersed the species towards the coast of north-eastern Brazil, where it was discovered by the Portuguese seafarers (Ascenso, 1986a). The Portuguese introduced the cashew into East Africa and the west coast of India probably during the first half of the 16th century. Since then it has spread and become naturalised in many other tropical countries mainly in coastal areas (Fig.1.1)(Agnoloni &

Giuliani, 1977; Ascenso, 1986a).

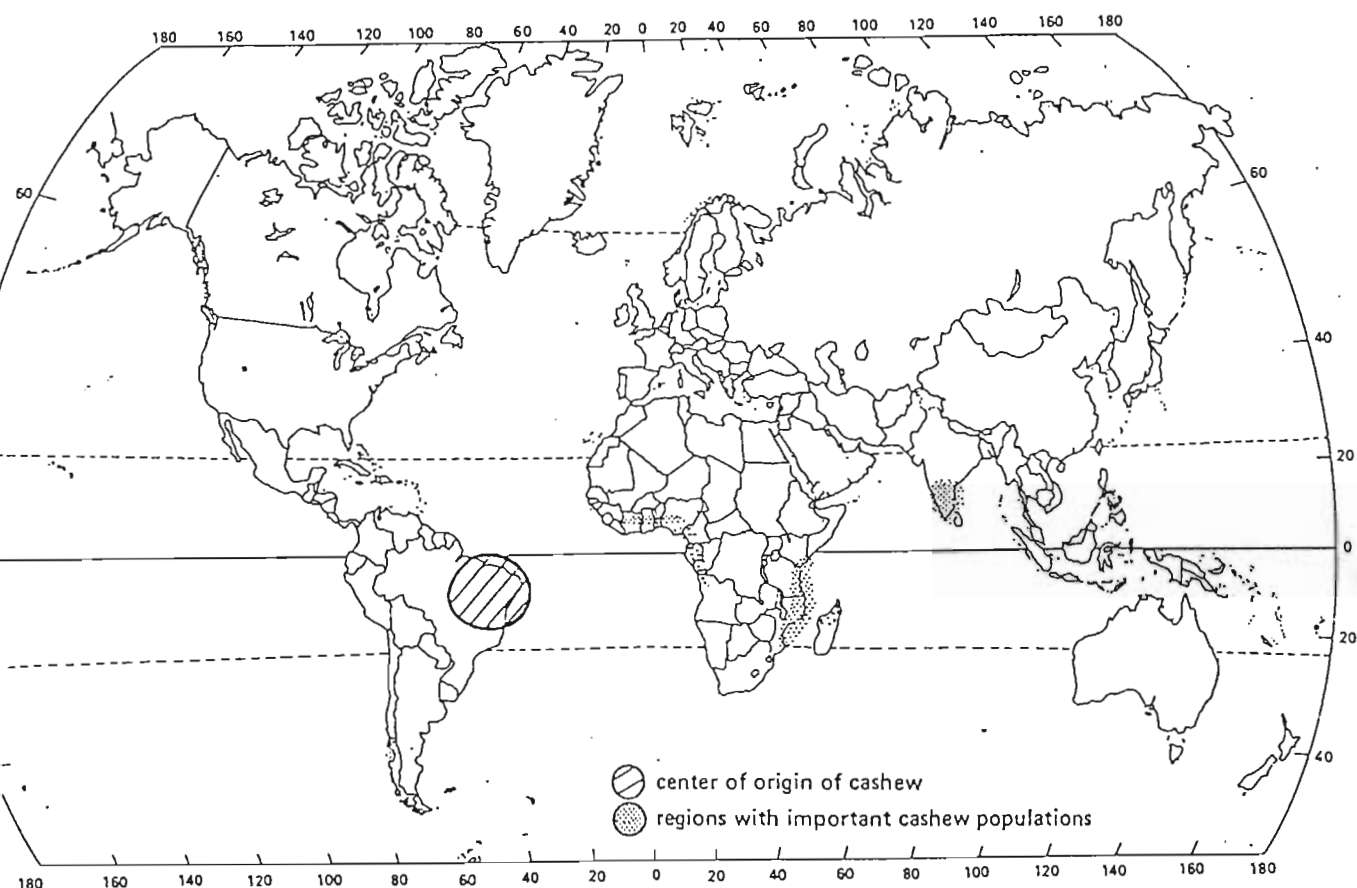


Fig. 1.1. Centre of origin of cashew and areas of major production (Ohler, 1977).

Most cashew nuts are collected by peasants from semi-wild trees or from small groves around their dwellings. Plantation scale cultivation started during the early 1970's in Mozambique where large plantations were established by the Anglo American Corporation together with Tiger Oats, National Milling and an Italian concern, Oltremare (Coetzee, 1972). At the same time large scale plantings began in Brazil and a while later in India (Ohler, 1979).

Cashews are grown commercially chiefly for their kernels, although cashew nut shell liquid (CNSL) and apples may be valuable by-products (Ascenso, 1986a). The major producers of cashew are Mozambique, India, Brazil, Tanzania and Kenya. The major consumers of cashew nuts are USA (45%), CIS (10-26%), Germany, Canada (5%), Japan, UK (4%), Netherlands and Australia (4%), these countries collectively making up about 90% of world consumption (Nair et al., 1979; Gill & Duffus, 1987,

Duncan, 1989). Cashews are traded in US\$ and world prices (\pm US\$ 3.00 per pound) are based on the US import prices. Kernel prices have increased significantly (9% p.a. from 1976 to 1986), indicating decreased supplies and high demand for the nut. Cashews make up about 7% of the edible nut market (peanut - 47%; almonds - 5.6%) (Duncan, 1989).

Cashew production worldwide has not lived up to expectations during the last decade or two (Fig. 1.2). This was probably due to the war and consequent breakdown of the marketing system in Mozambique, tree decline due to old age, increased disease incidence, and the higher returns from annual crops in Tanzania and Kenya (Brown, Minja & Hamad, 1984), and labour problems in India (Ohler, 1979). One of the most important reasons, however, is the fact that most cashew plantings are grown on a third world basis, resulting in poor management and related problems.

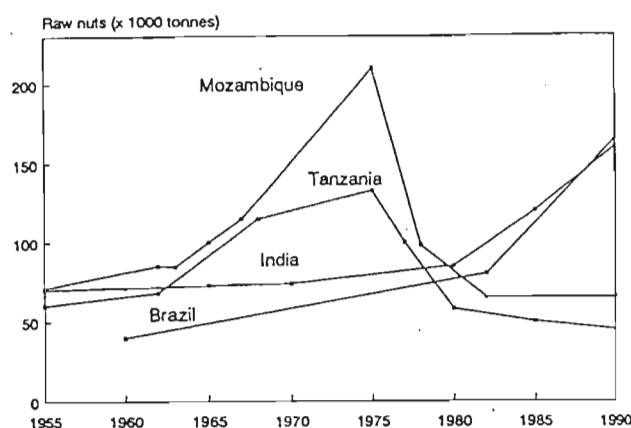


Fig. 1.2. Production (tonnes) of raw nuts by the major cashew producers (Duncan, 1989).

It is interesting to note that Mozambique's greatest foreign exchange earner was denounced as a source of vice and ruin at the turn of the century. For a while its cultivation was prohibited; later on, plantations were heavily taxed in an effort to prevent the consumption of the highly intoxicating liquor distilled from the cashew apple (Morton & Venning, 1972).

Cashews are not grown commercially in South Africa although trees have been established in a number of sites in Natal and in the Northern and Eastern Transvaal (Joubert & Thomas, 1965; Ascenso, 1988). Some problems, mainly climate related have been identified in Maputaland so far, viz. a marginal climate in terms of semi-arid monsoonal tropicity, flower diseases and the resulting low yields being a major limiting factor in Maputaland, but also a lack of suitable clonal material. Three main strategies are available to counter this problem, viz. selection and breeding for trees tolerant to a marginally tropical climate and to the blossom diseases; chemical control; and tree manipulation to shift flowering out of the period of high pathogenic activity. The latter has been attempted in this study. Other questions which arose were: what are the chances of achieving an economically viable cashew industry in South Africa; what is the state of scientific research into this species; and what can be done about

the problems facing the industry? The economically biased periodical, "Effective Farming", suggested that the time is right for a closer look at the potential for cashews in South Africa (Harrison, 1989). This thesis will attempt to deal with these and other questions.

CHAPTER 2 : LITERATURE REVIEW

The cashew, being overwhelmingly grown as a peasant crop, with minimal management inputs, in lowland tropical monsoonal climates in third world countries, has not received as much scientific scrutiny as, for example, even the mango. Rigorous scientific research on this crop is difficult to find. Furthermore, most of the literature has been published in often obscure, industry-related journals and difficult-to-access reports.

2.1 ECOLOGICAL REQUIREMENTS

2.1.1 *Latitude*

The most probable region of origin of cashew in north eastern Brazil, lies between the latitudes of 0° and 10° South. Cashews can be found growing from southern Florida at about 25°N, to northern Transvaal and some areas of Northern Natal at 27 to 28°S. At these extremes there is no commercial production. Inhambane, Mozambique, at about 23°S, is probably the region of commercial cultivation furthest from the equator. Here the climate is influenced by the warm Mozambique current flowing from the north. Most other regions where the cashew is an important crop, fall between the latitudes 15°N and S (Ohler, 1979). The areas in South Africa where cashew cultivation shows most promise are the hot, semi-arid low-lying regions within the latitudes 22°S and 28°S (Ascenso, 1988).

2.1.2 *Altitude*

The altitude at which cashews can be grown depends on latitude. In Songea, Tanzania, at 10°S, the cashew is grown up to about 1000 m. On the other hand, in Assam, India at 25°N, conditions were not favourable for the crop at altitudes above 170 m (Ohler, 1979). Latitude, altitude and the distance from the sea at which cashew can be commercially grown are important only insofar as they affect factors such as climate and soils (Anon., 1978). Lower temperatures at higher altitudes and latitudes affect the development of the tree. In Tanzania the harvest at higher altitudes begins some weeks later than at the coast, which means that early rains may spoil the unharvested nut (Ohler, 1979).

2.1.3 *Photoperiodicity*

Although no data were available, Ohler (1979) suggested that the cashew might be expected to display equatorial behaviour in this respect, viz. equal day and night lengths being most favourable for flower induction. However, from observations in various locations it seems that flowering of cashew is influenced more by the occurrence of rainy and dry seasons, and possibly by cool spells, than by daylength.

2.1.4 *Temperature*

The cashew is a plant of the hot dry tropics (or a thermoxerochimenic climate) (Agnoloni & Giuliani,

1977). Daily temperatures may exceed 40 °C in its native habitat as well as in northern Mozambique (Ohler, 1979). However, very high temperatures (39 to 42°C) during the marble stage of fruit development causes fruit drop (Nambiar & Thankamma Pillai, 1985). A monthly average temperature of 27°C is considered optimum (Ohler, 1979; Wait & Jamieson, 1986) while optimum average maxima and minima are 38° and 18° respectively (Agnoloni & Giuliani, 1977). The absolute minima and maxima for cashews were reported to be 5°C and 45°C respectively (Ohler, 1979). Temperatures should be suitably high and uniform throughout the year (Table 2.1) (Staples, undated), although it may not be disadvantageous to have a pre-blossom cool period to synchronise flowering.

Table 2.1. Mean daily maximum and minimum temperatures and relative humidity range in dry and wet season months in four locations considered to be favourable for commercial cashew growing (Staples, undated; Ascenso, 1988; IDC, 1992).

	SITE			
	NM	NA	NB	*ME
ALTITUDE (m)	171	10	60	70
MINIMA (°C)				
Dry season	16-20	15-20	18-20	11-18
Wet season	18-22	22-24	19-21	16-22
MAXIMA (°C)				
Dry season	28-35	31-35	32-33	24-28
Wet season	32-36	32-36	30-32	25-31
REL. HUMIDITY (%)				
Dry season				
Wet season	52-73 54-74	61-71 69-87	73-77 72-83	50-63 59-68

NM = Northern Mozambique, NA = Northern Australia, NB = North-eastern Brazil, ME = Mosi Estate (Maputaland, RSA).

* Data from 7 years

The cashew, particularly when young, is very sensitive to frost, and 7°C is considered the minimum temperature for cashew production. The duration of the cold period is also of importance; cashew trees may withstand temperatures approaching 0°C for short periods, but one could hardly expect to grow them economically in areas with a mean annual temperature not higher than 20°C (Ohler, 1979). Cool spring conditions tend to delay flowering (Wait & Jamieson, 1986).

2.1.5 Rainfall

It has been stated that cashew can be grown under conditions of rainfall ranging from 500 to 4000 mm per annum, but no mention has been made of yields under such extreme conditions. Data on the water requirement of cashews were not available but there were indications that it was higher than was often assumed (Ohler, 1979). Wait & Jamieson (1986) considered 1500 to 2000mm, provided by rain or

irrigation, to be optimum in the dry tropics of northern Australia. Agnoloni & Giuliani (1977) stated that for good fruiting, the cashew required an annual rainfall of 800 - 1600 mm in 5 to 7 months with a 7 to 5 month dry period. Higher rainfall than this may lead to excessive vegetative development accompanied by a dearth of flowers and fruits.

Cashews can be very resistant to drought, but only under conditions where the roots can penetrate deeply into the soil and draw from water reserves that are not available to other crops (Ohler, 1979). Insufficient rain however, leads to irregular flowering and fruit-setting (Agnoloni & Giuliani, 1977). Cashews cannot tolerate waterlogging (Staples, undated; Nambiar & Thankamma Pillai, 1985).

Another factor to note in the survival of the cashew plant is its marked competitiveness for water and nutrients both with weeds and other cashew plants. Given a wide spacing and frequent hoeing, the cashew can survive and produce using only the water reserves in the soil in areas with only 900 mm of rain per annum, even when evaporation from a class A pan was recorded up to close to 2 000 mm a year (Argles, 1969).

Ideally there should be no rain from the outset of flowering until harvesting is completed. Rain during flowering results in the development of anthracnose (*Colletotrichum gloeosporioides*), which causes flower drop. During nut and apple development, rain causes rots and severe crop losses. Rain during the harvesting period when nuts are on the ground causes them to deteriorate rapidly. Sprouting occurs after about 4 days of damp conditions (Wait & Jamieson, 1986). Heavy rains during flowering affected yields adversely while light rains had no harmful effect on flowers (Ohler, 1979). Heavy dews in Maputaland may result in heavy powdery mildew (*Oidium anacardi*) infections which can cause serious damage to flowers and young fruit and leaves (Cunliffe¹, pers. comm., 1990). The rainfall distributions of three locations where cashew is cultivated are presented in Table 2.2.

Table 2.2. Rainfall distribution from north-eastern Brazil, western Zambia and Mosi Research Farm (MRF) (IDC, 1992).

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
N.E.Brazil*	214	313	526	473	216	251	69	25	30	8	28	112	1985
W.Zambia**	223	218	147	46	2	1	0	0	1	28	122	213	1001
MRF***	120	103	105	56	40	28	12	9	25	51	59	83	695

* Data from 4 years

** Data from 17 Years

*** Data from 7 years.

¹. Cunliffe, R.J., Former Manager, Mosi Estate, Private Bag 330, Kwangwanase, Ingwavuma District, KwaZulu.

The total amount of rainfall in the rainy season is not the only factor determining the availability of water (eg. presence of water table, high relative humidity, winds, etc). Therefore figures of optimal rainfall cannot be given without taking other growing conditions into account. Ecological conditions in general should be used as a guide to the suitability of an area for cashew cultivation.

2.1.6 *Relative Humidity*

No exact figures were available on optimum relative humidity (RH) conditions, but the range is fairly wide. Extremely dry air during the flowering period may wither the flowers and decrease yields. On the other hand, high relative humidity is unfavourable as it favours the growth of fungi such as *Colletotrichum gloeosporioides*, which seriously affects cashews in humid areas. Humid climates tend to harbour more insect pests than dry climates (Ohler, 1979). On the other hand, relatively high humidity during part of the dry season, in areas where the rainfall drops to the lower limit for cashew cultivation, enables the plant to balance its water requirements and get over the critical period much better (Agnoloni & Giuliani, 1977).

Cashews are sometimes said to be "essentially coastal trees" (Mutter & Bigger, 1962) and that they should be able to "smell the sea" (Joubert & Thomas, 1965), but this is not entirely true. Trees growing in the drier interior of Tanzania look much healthier than those growing at the coast. In Brazil, cashews grow well more than 1000 km from the coast (Ohler, 1979). In Mexico, Venezuela, Zimbabwe, Malawi, and Zambia they are also grown at considerable distances from the coast (Agnoloni & Giuliani, 1977).

2.1.7 *Sunshine*

It can be assumed that cashew, being adapted to climates with long dry seasons and low relative humidity, does best with high sunshine hours throughout the year (Ohler, 1979). According to Ascenso, (1988) it is estimated that cashews require not less than 1500 - 2500 hours of annual sunshine.

Where sunshine records are not available the cloud cover records have been used. In West Africa, for instance, the area favourable for cashew growing is determined by a mean annual cloud-cover of 0.4, with 0.3 being particularly favourable and mean annual cloud-cover of 0.5 roughly coinciding with the absolute limit for cultivation (Lefebvre, Goujon, Leturcq, Marcellesi & Praloran, 1973).

2.1.8 *Wind*

The majority of cashew-growing areas lying close to the sea are considerably exposed to wind. If winds with a velocity greater than 25 km h⁻¹ occur in an area where cashews are grown, then windbreaks should be established (Ascenso, 1988). The potential soil erosive effects of high velocity winds should not be underestimated. Mechanical damage to trees may also occur in such areas. At Makatini Research Station the author observed some trees that had been blown over and some with split

crotches, thus emphasising the need for adequate windbreaks before the trees become too big. At Mosi Estate the wind blows at speeds greater than 20 km h⁻¹ for about 12 per cent of the time (Table 2.3), and windbreaks are therefore essential.

Exceptionally strong winds may cause flower drop and fruit fall and in some cases may be the major limiting factor to cashew cultivation, as is the case in the Antilles and the Fiji Islands. Dry winds such as the Harmattan in West Africa (and the 'Berg winds' in southern Africa) increase evapotranspiration and cause physiological imbalances during the critical period of flowering and fruit-setting. Salt-laden air may lead to scorching of buds and leaves (Agnoloni & Giuliani, 1977).

Table 2.3. Frequency of wind for specified wind classes at Mosi Estate for the period May 1987 to January 1989 (IDC, 1992).

Wind speed classes (km h ⁻¹)						
Calms	0 - 5	5 - 12	12 - 19	20 - 28	29 - 39	>39
13.87%	11.79%	33.77%	28.26%	10.84	1.4	0.02

2.1.9 Soil

The statement "cashew is a crop of the marginal lands" (Nair *et al.*, 1979) and notions such as "cashew is very modest in its soil requirements and can adapt itself to varying soil conditions without impairing productivity" appear many times in the literature. Great harm has been done to cashew culture by these statements, because this resulted in the worst soils being selected for cashew, where no other crop could give an economic return (Ohler, 1979).

Cashews can grow on poor or stony soil, probably because of their extensive root systems, greatly increasing the available volume of soil from which they can draw their nutrients and water. Reasonable yields are obtained as long as there is sufficient soil between the stones to allow the roots to penetrate, especially if deeper, more favourable soil layers can be reached (Ohler, 1979). Agnoloni & Giuliani (1977) wrote that the cashew is a sand-loving plant with a preference for coastal plains. Semi-spontaneous cashew plantations in various parts of the monsoonal tropics are found on the sands of the coastal fringe. Despite the obvious limitations of chemical fertility, it appears that the cashew is more sensitive to the physical than the chemical properties of the soil.

Until recently there has been practically no research effort to evolve new cashew cultivars with high yield potential or to assess the yield potential of existing cultivars under different soil fertility levels. However, what is generally true for other crops should also apply to cashew (Nair *et al.*, 1979). Mahapatra & Bhujan (1974) prepared a useful rating chart for land selection for cashew in India which

could be used as a guideline for most other parts of the world (Appendix II). Hackett (1990) summarised the ecological requirements of cashew in the form of what he termed a "crop environment matrix (CEM)" (Appendix III), which classifies possible areas for cashew growing according to the worst limitation.

A distinction should be drawn between soils where the plant can survive, but little more, and soil that favours cashew plantations with high output in quantity and quality (Agnoloni & Giuliani, 1977). The best soils are deep friable, well drained, sandy loam soils without a hardpan. The phreatic water level should, ideally, be at a depth of 5 to 10 m. On badly drained land the water table may be too high in the rainy season resulting in superficial root growth. The trees would then suffer from drought stress in the dry season when the water table drops (Ohler, 1979).

Cashews sometimes grow very near the beach suggesting some tolerance to soil salinity. A cashew tree on Mafia Island, Tanzania, was observed growing near a mangrove where at high-tide the sea water came very close to the trunk. This tree had a healthy appearance in spite of the salty water (Ohler, 1979). Apart from these observations, cashews cannot tolerate soil with a strong brackish water-bearing stratum (Agnoloni & Giuliani, 1977; Ohler, 1979). Laboratory trials have indicated that cashew has only slight tolerance for soil salinity, and also that differences in tolerance exist between cashew trees (Rocchetti, 1970).

The soils of the Makatini flats, where commercial cashew cultivation is a possibility are variable in depth, very sandy, non calcareous, highly leached and generally of low agricultural value. The grey sandy soils of the interdune areas are characterised by a relatively high water table (1.5 m to 2 m) resulting in possible waterlogging, especially in wet years. In some places, however, the water level may be as deep as 30m. These soils consist of approximately 90% sand with 1 to 8% clay and low fertility. With adequate soil management including fertilizer application, cashews could be grown quite satisfactorily on the Makatini Flats. Further north at Mosi Estate in Maputoland, soil conditions were found to be similar to those at Makatini, but the water table varied from 0.7 to 1.3 m and there was gleyed B horizon present (Ascenso, 1988). Soil water was found to have a very high iron sulphite content, but the effect of this high concentration on cashew growth and development has not yet been determined (Cunliffe², pers. comm., 1990). The high water table in these areas may reduce the need for irrigation and may require unique management practices.

The areas with the most suitable climatic and soil conditions for cashew cultivation in South Africa are the hot areas of northern Zululand, Maputaland and the Eastern and Northern Transvaal lowveld. At

². Cunliffe, R.J., Former Manager, Mosi Estate, Private Bag 330, Kwangwanase, Ingwavuma District, KwaZulu.

first sight it appears that South Africa is marginal for cashew production when compared to the ideal conditions (Appendix II and III), mainly because of relatively cool and wet winters and low total rainfall. However, the history of tropical crops such as mangoes, citrus and bananas has shown that they can be successfully cultivated in subtropical regions after adaptable cultivars were found, and orchard management practices developed, for a given set of conditions (Ascenso, 1988).

2.2 GROWTH AND DEVELOPMENT

2.2.1 *Vegetative*

2.2.1.1 Aerial Growth

2.2.1.1.1 General Description

The cashew tree is an evergreen perennial. When growing under favourable conditions the stem is erect and the canopy symmetrical, mostly dome shaped. The tree may grow as tall as 15m. However, trees growing under harsh conditions tend to have distorted branches and shorter stems (Ohler, 1979; Wait & Jamieson, 1986). It also seems that there is some variety in tree shape, some trees growing tall with a conical shape, most others having a more sprawling growth habit (Morton, 1970; Ohler, 1979).

The tree rapidly develops its canopy, bearing its foliage peripherally. Tsakiris and Northwood (1967) and Goldson (1973) measured canopy size in relation to age (Table 2.4). The canopy diameter is of particular importance when considering plant arrangements (to be discussed later) (van Eijnatten & Abubaker, 1983). It appears that under reasonably favourable conditions young trees may grow at a rate of 1 m per year, their canopy diameter increasing by about 1.5 to 2.0 m per year for the first five years, after which growth may slow down. Branching begins close to the ground, the lower branches resting on the ground a few metres from the trunk - branches of older trees may creep over the ground over some distance, sometimes rooting where they touch (Davis, 1961) making this tree suitable for soil protection against erosion, for which it is often primarily grown. However this characteristic makes regular harvesting difficult and therefore the lower branches are usually cut away (Ohler, 1979).

Table 2.4. Canopy measurements of cashew trees at Mtwapa, Kenya over fifteen years (Goldson, 1973).

Age of tree (year)	Canopy measurement		Age of tree (year)	Canopy measurement	
	Diameter (m)	Height (m)		Diameter (m)	Height (m)
1	1.8	1.1	9	9.6	6.8
2	3.3	2.2	10	10.0	7.0
3	4.9	3.3	11	10.3	7.2
4	6.2	4.2	12	10.5	7.3
5	7.2	5.1	13	10.8	7.4
6	7.8	5.8	14	11.0	7.4
7	8.5	6.1	15	11.37	7.5
8	9.2	6.3			

2.2.1.1.2 Growth Flushes

Argles (1969) wrote that two or three flushes are usually observed in a bearing cashew tree, even though under favourable conditions some unsynchronised shoot growth may occur throughout the year. The pattern of growth can be described as one of indeterminate flushing consisting of a generative flower flush and a vegetative flush, which always develops soon after the main crop has matured.

2.2.1.1.3 Tree Architecture

The tree architecture conforms to Scarrone's model which is determined by "an orthotropic rhythmically active terminal meristem which produces an indeterminate trunk bearing tiers of branches, each branch-complex orthotropic and sympodially branched as a result of terminal flowering". The monopodial trunk and the complexity of the orthotropic branches in this model correspond to adaptation to certain not yet completely "mature" forest environments (Halle, Oldeman & Tomlinson, 1978).

Dasarathi (1958) reported two types of branching in cashew, intensive and extensive. The intensive shoot grows to a length of about 25 to 30 cm and terminates in a panicle. Simultaneously, three to eight laterals arise within 10 to 15 cm of the apex. Some of these laterals may terminate in panicles during the same flowering season, repeating the same growth pattern. This results in the well covered bushy appearance of the tree. The extensive shoot grows about 20 to 30 cm and rests. A bud sprouts 5 to 8 cm below the apex and grows out further. This process of growth continues for two or three years without flowering. Both kinds of flowering are observed in all trees, but one type will dominate in a tree. High yielding trees had more than 60% intensive branches whereas low yielders had less than 20%.

2.2.1.2 Roots

The root system of a fully grown cashew tree consists of a tap root, which atrophies at a fairly shallow depth, and an extensive network of primary and secondary roots. This system covers a large enough diameter to ensure that the plant gets what it needs in terms of nutrition and water, even during prolonged periods of drought (Agnoloni & Giuliani, 1977). Seedlings form a tap root reaching a depth of 1.5 to 2 times the height of the plant during the first four months (Anon., 1979). Hassan & Rao (1957) found that no lateral roots were produced during the first three months of growth, and fibrous roots were only well developed by the age of 10 months.

Tsakiris & Northwood (1967) observed the spread of lateral roots of cashew in Tanzania (Table 2.5) and found that the roots reached far beyond the canopy spread of the trees during the early years of growth. This meant that under such conditions, trees planted with a 12 m spacing would have their root systems intermingling at an age of four to five years, when the canopies still have a wide space between them. The horizontal laterals tended to concentrate in and fully exploit the top 12 cm of soil.

Observations by van Eijnatten & Abubaker (1983) on mature trees at Mtwapa, Kenya, showed that sinker roots grew from laterals within about 3 m from the trunk. Lateral roots thinned out after this and those emerging beyond the drip-line of the canopy at 6 m from the trunk were few and very thin. The rooting volume therefore seemed to be confined mostly to below the canopy.

Table 2.5. Lateral root spread of cashew trees in East Africa with age (Adapted from Tsakiris & Northwood, 1967).

Tree age (years)	Root depth (m)	Root spread (m)
1.5	1.0	1.2
2.5	2.0	4.6
3.5	2.3	5.6
4.5	5.0	--
6	--	7.3

2.2.2 *Reproduction*

2.2.2.1 Flowering

The cashew is andromonoecious or polygamous, with male and perfect or hermaphrodite flowers being found on the same panicle of a cashew plant (Copeland, 1961; Purseglove, 1968; Fernandes & Fernandes, 1969; Agnoloni & Giuliani, 1977). Flowering in cashew is usually profuse; about 85 to 90% of the shoots of a bearing tree flower every year (Rao, 1956; Dasarathi, 1958).

2.2.2.1.1 Description

2.2.2.1.1.1 Inflorescence

The flowers of *A. occidentale* are borne in terminal panicles (Fig. 2.1) (Ascenso & Mota, 1972a), although Copeland (1961) called the inflorescence a panicle-like cluster, each branch of the cluster bearing a terminal flower subtended immediately by two or more bracts. From the axils of the bracts grow further bracted flower-stalks. Thus, he concluded, the ultimate cluster of flowers is a typical monochasial cyme, and the apparent panicle is actually a thyrses. Barfod (1988) took this further by classifying the inflorescence as "monoletic, conjunct heterocladic pleiothyrsoids" (complex thyrses, composed of cymes, with a terminal flower on the inflorescence axis, determinate flowering). Moncur (1988) wrote that as a general rule the terminal flower of each panicle branch is perfect while the lateral flowers are male.

Depending on the vigour of the plant each panicle carries from three to 11 floral peduncles, each of which carries 40 to 100 individual florets, making a total of 120 to 1100 flowers per inflorescence with an average of 329 (Morada, 1941). However, the number of flowers per panicle varies with location and growing conditions. Damodaran, Abraham & Alexander (1966) counted 200 to 1600 with a mean of 486 flowers per healthy inflorescence and Moncur (1988) reported 1 to 200 flowers per panicle.

The ratio of hermaphrodite to male flowers varies considerably during development and between locations. In Jamaica, the ratio averaged from 1 : 3.7 (Northwood, 1966) to 1 : 8 (Morada, 1941; Anon., 1960), to 1 : 6.5 in Tanzania (Mutter & Bigger, 1962), to 1 : 28 (Anon., 1960) and 1 : 500 during the first male phase of flowering (Pavithran & Ravindranathan, 1976).



Fig. 2.1. *Anacardium occidentale*: Cashew. A, flowering branch ($\times \frac{1}{3}$); B, male flower in longitudinal section ($\times 3$); C, hermaphrodite flower in longitudinal section ($\times 3$); D, developing fruit ($\times 2$); E, fruit and apple ($\times \frac{1}{3}$) (Purselove, 1968).

2.2.2.1.1.2 Flowers

The scented flowers are small and white to light green when just opened but within a few days they turn pink. Each perfect flower stands on a pedicel about 2 mm long. In staminate flowers the pedicel and the cylindrical part of the perianth are more slender than in the perfect flower (Copeland, 1961). Therefore on the same tree perfect flowers are larger than the male flowers. Petals and sepals alternate

and there are usually five of each (ie.the cashew flower is typically pentamerous). The petals, more than 10 mm long, lanceolate (Fig. 2.1) and downy or pubescent on both surfaces, arise from within the tube formed by the separate, oblong, acute, imbricate, overlapping sepals around the pedicel. At anthesis the petals are curved back bringing the tips to the level of the receptacle (Agnoloni & Giuliani, 1977; Nair *et al.*, 1979; Ohler, 1979).

All flowers have one ovary, style and stigma (which are rudimentary in staminate flowers). The simple style springs from the distal margin of the ovary tapering to a slightly expanded stigma. The size varies from 1 to 2 mm in staminate and 6 to 12 mm for perfect flowers. The pistil is dorsiventral and the ovary is superior, laterally compressed, with one end broader than the other and directed towards the large stamen. The ovary contains a single locule and a single apotropous ovule (Nair *et al.*, 1979; Ohler, 1979). Ascenso & Mota (1972b) suggested that the staminate flowers are derived from the ancestral hermaphrodite flowers by gradual reduction and loss of function of the gynoecium.

Both perfect and staminate flowers have eight to 11 stamens of unequal size. The male flowers usually bear one large (6 to 8 mm) exerted stamen and nine small (3 to 5 mm) inserted ones (sometimes referred to as staminodes), although there may be as few as five. Occasionally, two large exerted stamens or some of an intermediate size are present. The large stamen and most of the small stamens produce pollen, although compared to the large one, the small stamens contain only a few pollen grains. The anthers are basifixed, bilobed and dehiscent between the two pollen sacs of each lobe. The anther is rounded and pink coloured, turning grey at dehiscence (Northwood, 1966; Nair *et al.*, 1979; Ohler, 1979; Moncur & Wait, 1986).

In hermaphrodite flowers the staminal arrangement is similar to that of the male flowers. The major stamen protrudes less than in male flowers (Copeland, 1961) and the pistil is normally longer than the large stamen, but occasionally it is shorter or of equal size. In flowers with equal-sized major stamen and pistil, the chances of self-pollination are increased, but these are not common (Northwood, 1966). Research in India indicated that higher fruit set occurs when the distance between the stigma and the anthers is small (3 to 4 mm) (Agnoloni & Giuliani, 1977).

Northwood (1966) found a third type of flower which could be considered degenerate because the reproductive organs were reduced and infertile. Its only function appeared to be that of insect attraction.

2.2.2.1.2 Age of Flowering

The age at which a cashew tree starts flowering is influenced by growing conditions and probably also by genetic factors. Under favourable growing conditions, the first crop worth harvesting is produced

at the age of three years. However the production of flowers and a few fruits usually take place in the second year of growth and in exceptional cases trees may produce flowers in the first year of growth (Ohler, 1979).

2.2.2.1.3 Flowering Season

Northwood (1966) noted that some trees were consistently early bearers in the fruiting period and others later bearers. This characteristic was likely to be inherited. Unlike the mango, which bears its crop on the past season's wood, the cashew produces flowers on the current season's flushes (Rao & Hassan, 1957) after the growth flush at the end of the rainy season. However, Ohler (1979) saw some trees in Malaysia developing terminal inflorescences without any previous shoot growth. Cashew trees need some stress to synchronise flower induction. Under conditions of evenly distributed rainfall throughout the year flowering may occur continuously during the year. In climates with two dry periods, flowering may take place twice a year.

Table 2.6. Comparisons of flowering periods of cashew in different African regions (modified from Staples, undated; Agnoloni & Giuliani, 1977; Nair *et al.*, 1979).

Region	Flowering Period	Peak Flowering
Tanzania	June - November	August - September
Mozambique	July - December	October
Maputaland		
*Gazini	August - March	Late September and November/December
*Mbazwana	August - March	Late September/October
*Makatini	September - March	September/October and December/January

* Data based on three years of observations.

The flowering season may differ slightly from year to year and usually extends over a period of several months. Due to temperature limitations and genetic variability, the main flowering period extends from August to March in northern Zululand and Maputaland (Table 2.6) which coincides with the rainy season, leading to problems due to blossom diseases. At other times of the year a few inflorescences may be seen but these are of little significance (Staples, undated).

2.2.2.1.4 Daily Time of Opening of Flowers

Northwood (1966) observed the time of day when individual flowers opened in southern Tanzania. He found that 75% of the flowers opened between 08h30 and 14h40 and that the peak opening period was

from 11h00 to 12h30 (Fig. 2.2). A mean number of 6,5 flowers opened per day per inflorescence. On the east coast of India anthesis started as early as 01h00, with a peak between 08h00 and 12h00.

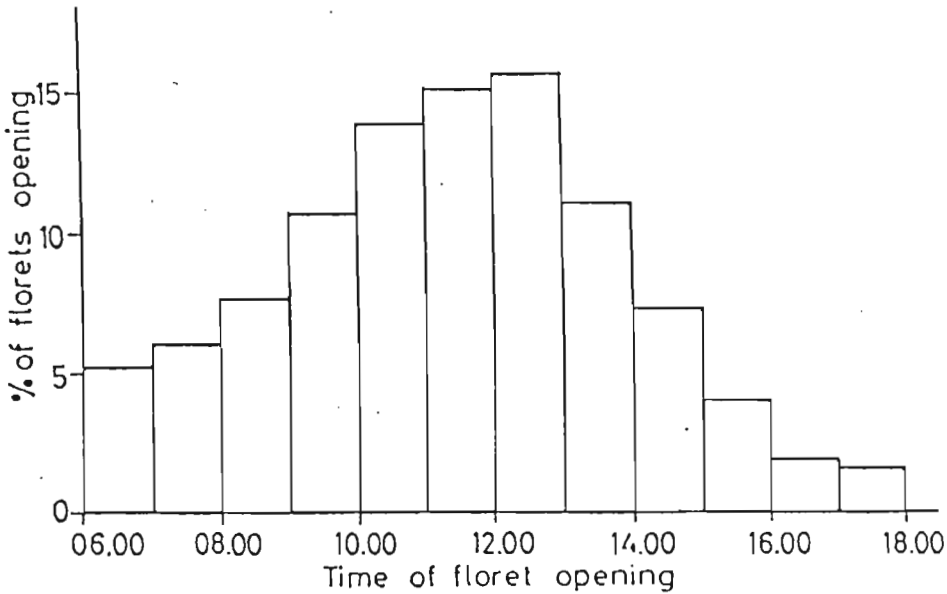


Fig. 2.2. Distribution of time of opening of cashew flowers from 06h00 to 18h00 (Northwood, 1966).

2.2.2.1.5 Flowering Process

2.2.2.1.5.1 Phenology

Conticini (1982) identified 12 phenological phases of cashew reproductive growth (Table 2.7) to standardise parameters for other researchers. Until then all cashew observations had been recorded by the day and month on which they were made. Clearly this led to some confusion when read in other parts of the world.

In a study on flowering patterns in India, flowering appeared in two or three distinct phases; (i) the first male phase with 19 to 100% male flowers, (ii) the mixed phase with nil to 60% male flowers and nil to 20% hermaphrodite flowers, and (iii) the second male phase with nil to 67% male flowers. The mean duration of flowering was measured as 84.4 days in which the duration of the first male phase was 2.4 days, the mixed phase 69.4 days and the second male phase 13 days (Pavithran & Ravindranathan, 1974).

Anthesis proceeds basipetally in the panicle, flowers in the younger branches opening first. A gradient in sex ratio at successive nodes of a panicle existed (Fig. 2.5), the percentage of perfect flowers increasing from the proximal to the distal end (Ashok, 1979; Subbaiah, 1983). In the bean, this was attributed to the basipetal gradient of endogenous auxin concentration in the shoot apex or the panicle

(Jacobs, 1950). This hormone has been shown to influence sex expression, fruit set, and abscission of immature fruits in cashew (Anon., 1975; Pappaiah, Hameed & Mustaffa, 1978; Ashok & Thimmaraju, 1981).

Table 2.7. Phenological phases during the flowering growth flush of cashew (Adapted from Conticini, 1982).

Phenological phase	Identifying characteristics
1	Shoot forming; young reddish brown leaves 2 to 3 cm long.
2	Shoot has developed; flower bud is visible; leaves larger and deeper red than in first phase.
3	Shoot 10 cm long; inflorescence length is 2 to 3 cm; largest leaves 10 to 12 cm long becoming more orange coloured at base.
4	Earliest four leaves become pale green and reach maximum size (13 to 17 cm long); inflorescence starts to open, the length being c. 8 to 10 cm; four or five branches in the panicle.
5	Rachis length reaches 12 to 14 cm long; inflorescence has opened further with five or six panicle laterals present; all leaves fully developed.
6	All leaves are green; rachis now 14 to 17 cm long and panicle laterals fully spread; some flowers are in anthesis.
7	c. 50% of the flowers are open and the panicle fully developed; the coriaceous leaves of shoots are dark green.
8	Full anthesis and fruit set starting.
9	Unpollinated flowers wither; fruit set continues and the first small fruits begin to swell (0.5 to 1 cm wide; 0.5 to 1.5 cm long).
10	Most of the set fruit has pinkish white thin skin; the red pedicel starts swelling to produce the pseudo-fruit.
11	Fruit and pseudo-fruit enlarge further; the skin of the fruit becomes harder and changes to a green colour
12	Fruit and apple fully developed and ripening continues.

2.2.2.1.5.2 Floral organogenesis

Initially, the flower buds are small, rounded and subtended by bract primordia (Fig. 2.3A), but as the buds enlarge they flatten (Fig. 2.3B). The first floral parts to initiate are the five sepals, followed by the five petals. The stamens initiate next on the periphery of the bud while the ovary develops in the centre (Fig. 2.3C). The ovary and one stamen soon become larger than the other stamens (Fig. 2.3C), with the style differentiating stigmatic tissue on its tip and the stamen differentiating anther lobes (Fig. 2.3D). The remaining nine stamens also differentiate anther lobes. The sepals and petals overlap and enlarge to form the corolla, which completely encloses the developing floral organs. The stigma is receptive as soon as the flower opens and remains so for only one day. The male flowers (Fig. 2.4) follow the same sequence of floral organogenesis as the hermaphrodite: sepals, petals, stamens and ovary.

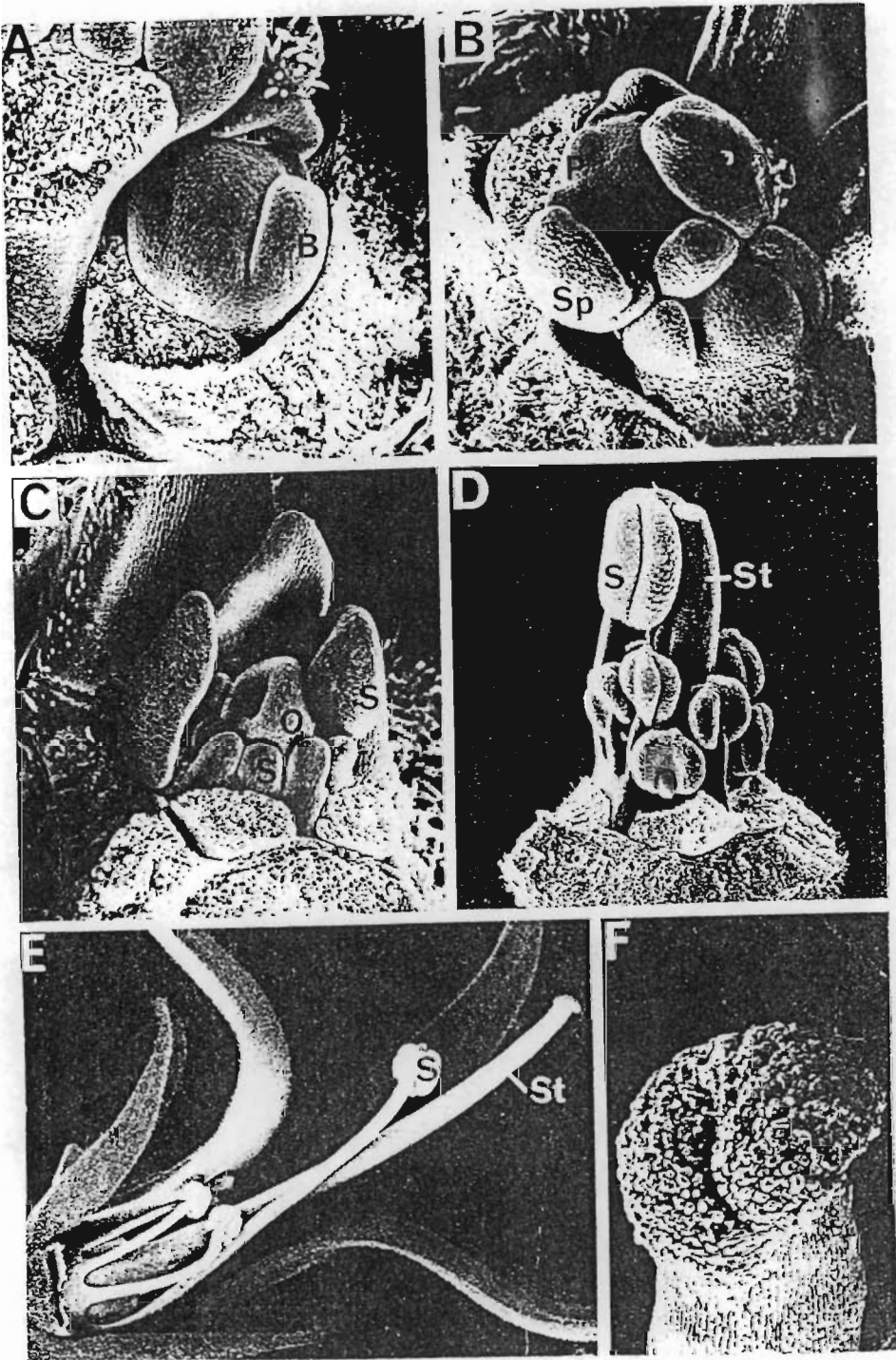


Fig. 2.3.

Development of the hermaphrodite cashew flower. **A.** Initial flower bud subtended by bracts (B) (x 160). **B.** Floral bud flattens and sepals (Sp) and petals (P) initiate (x 120). **C.** Stamens (S) initiate on periphery; ovary (O) in the centre. Note advanced development of one stamen (x 130). **D.** Growth and elongation of the large stamen (S) and style (St) compared to the remaining smaller stamens (x 30). **E.** Style (St) and large stamen (S) exert through corolla at anthesis (x 10). **F.** Receptive stigma (x 80) (Moncur & Wait, 1986).

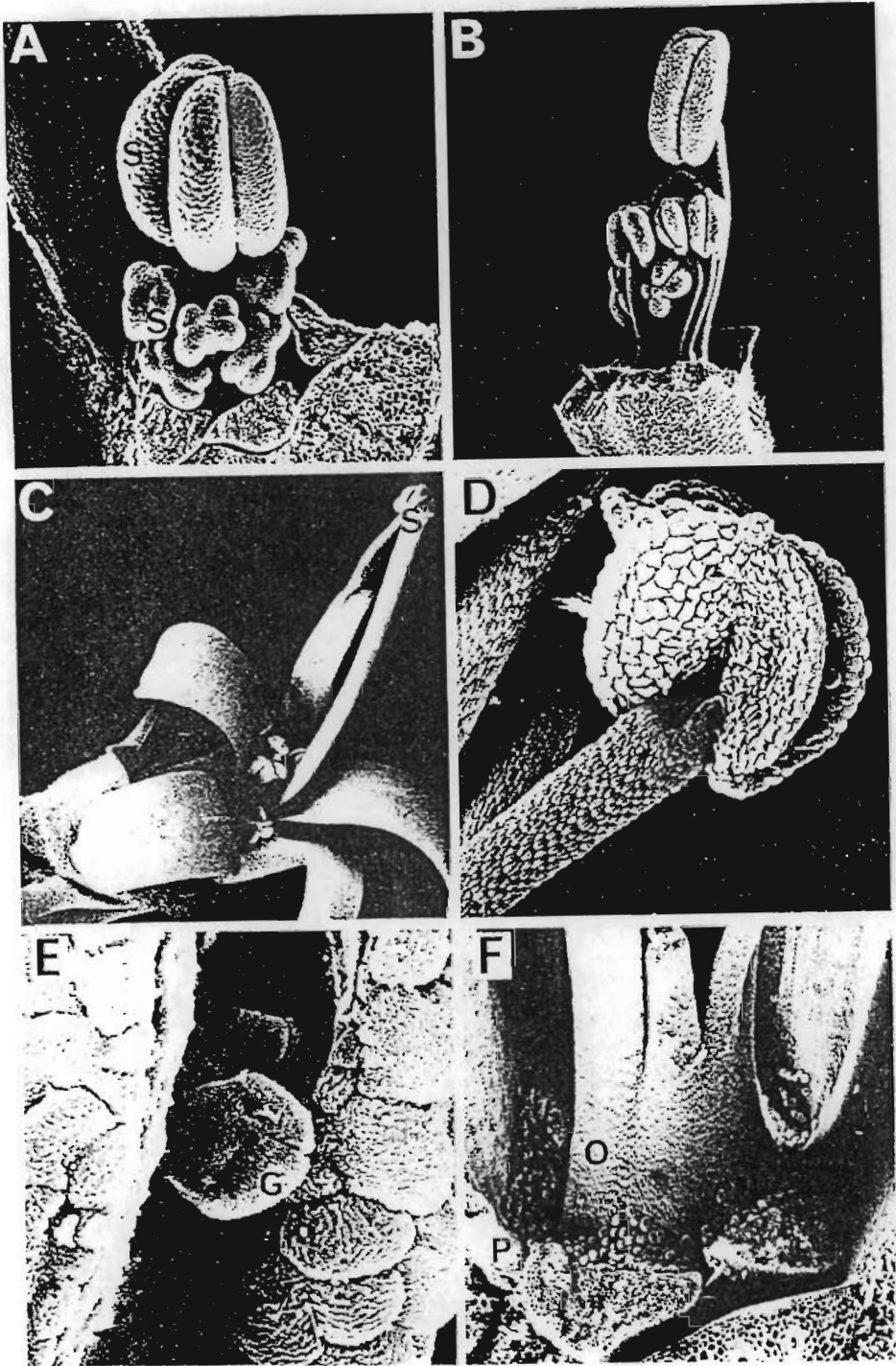


Fig. 2.4.

Development of the male cashew flower. **A.** Large and small stamens (S) differentiate anthers (x 60). **B.** All stamens elongate with the large stamen remaining dominant (x 35). **C.** Large stamen (S) exerts through corolla at anthesis (x 10). **D.** Small stamen dehiscing (x 100). **E.** Pollen grain (G) (x 750). **F.** Nectaries at base of petals (P) and ovary (O) in the hermaphrodite flower (x 50) (Moncur & Wait, 1986).

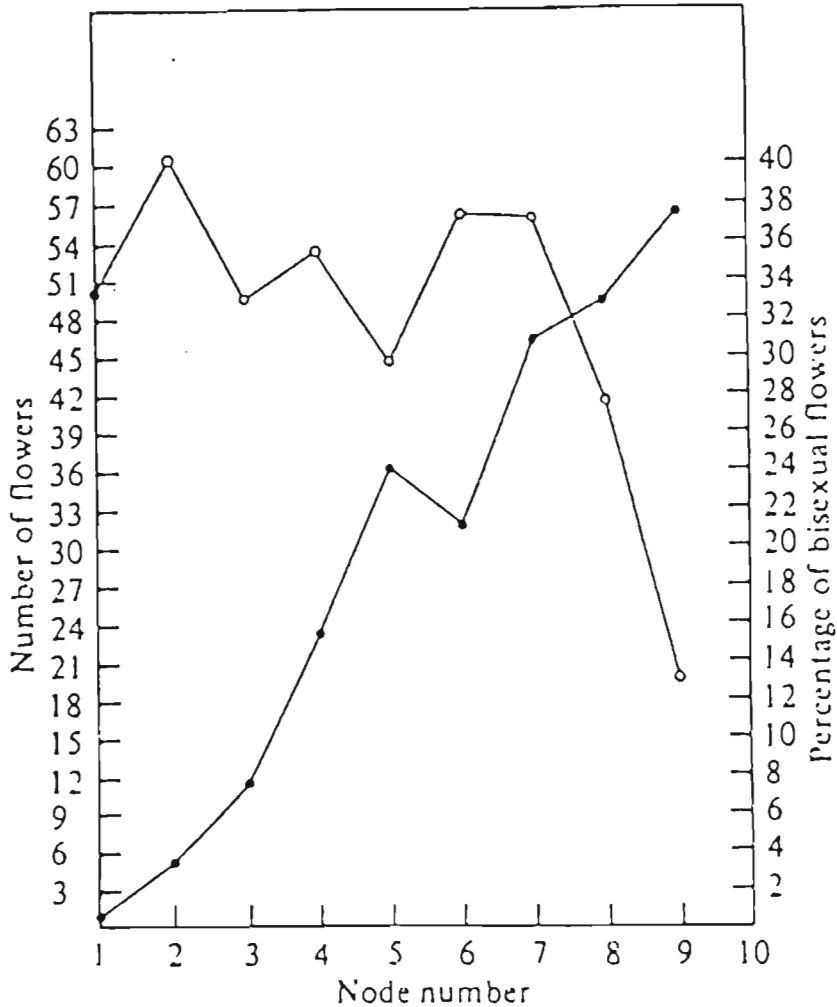


Fig. 2.5. Total number of flowers (o — o) and percentage of bisexual flowers (● — ●) at successive nodes of a panicle. The nodes are numbered from the proximal end (Subbaiah, 1983).

2.2.2.1.6 Pollination

The mode of pollination has been controversial. Rao & Hassan (1957) reported that the percentage of hermaphrodite flowers on Indian cashews were as low and variable as in mango with a mean of 4.0%, while the ultimate percentage of successful fruit set was only 3% of the total number of hermaphrodite flowers produced. The absence of adequate pollen in nature seemed to be responsible for this low set. Under artificial pollination the fruit set increased to 55 per cent. The role of insects was insignificant

as far as they were concerned, only ants being present. Wind, in their opinion, was most important in pollination.

On the other hand, Northwood (1966) found in Tanzania that there were large populations of flies and other winged insects capable of acting as pollinating agents. In the presence of these high populations of insects pollination was not a limiting factor in obtaining high yields. Ants crawling over the flowers could be responsible for considerable self-pollination of cashew. Free & Williams (1976) reported that at Mtwapa, Kenya, many cashew trees in the plantation had ants' nests beneath them and all had some ants visiting the flowers. This study leaves little doubt that cashew is entomophilous (Moncur & Wait, 1986).

The cashew flower has many features common to flowers pollinated by insects (Faegri & van der Pijl, 1971); scent, coloured petals, nectar and heavy sticky pollen. By contrast flowers pollinated by wind have small light pollen that is easily shed. Tests for cashew pollen presence in the air have proved negative (Northwood, 1966: Mohan, Kumaran, Murthy & Nayar, 1981). The small stigmatic surface is also not conducive to anemophily, but as the flower has a single ovule in a single ovary, successful pollination does not need large amounts of pollen on the stigma (Moncur & Wait, 1986). It has been suggested that bee colonies be introduced into orchards to increase fruit set (Smith, 1958).

Receptivity of the flowers began one day before anthesis and lasted about two days, with an optimum period soon after anthesis. Anthesis occurred from one to five hours after the flowers opened, depending considerably on temperature. Anthesis occurred more rapidly with flowers opening in the heat of the day than with those opening early in the morning (Northwood, 1966). It was also found that flowers opened earlier on the sunny side of the tree (Damodaran *et al.*, 1966). Pollen remains viable for two days (Ohler, 1979).

With stigmas being immediately receptive and there being a delay in anthesis, the chances for self pollination would tend to be reduced. The fact that the pistil is longer than the stamens would also tend to increase the chances of cross pollination. Selfing, using pollen from both male and hermaphrodite flowers, and hand pollination, was successful, but it was not known to what extent self incompatibility existed since only a few trees were used (Northwood, 1966). Moncur & Wait (1986) pointed out that even though the chances of autogamy were reduced, this did not rule out selfing. The chance of pollination between flowers of the same tree (geitogamy) may be equal to or greater than that of outcrossing (xenogamy). The amount of cross pollination has not been determined, but Westergaard & Kayumbo (1970) indicated a rate of up to 30% out-pollination. Some trees were also found to be self incompatible to a small extent, which suggested obligate cross-pollination in some lines.

2.2.2.2. Fruit and Pseudo-fruit

2.2.2.2.1 Description and Development

The kidney shaped nut is the true fruit of the cashew tree. It is attached to the pseudo-fruit or apple, the juicy swollen pedicel, which is about five to ten times as heavy as the nut when ripe. The nut is a true nut, with a single seed. The shell of the nut has a leathery exocarp, a hard and brittle endocarp, and a spongy mesocarp (Fig. 2.6) containing the cashew nut shell liquid (CNSL). The white kernel has a wrinkled surface and is covered by a reddish brown or pink testa (Agnoloni & Giuliani, 1977). As with other nuts, cashew is high in energy (2.35 kJ 100g⁻¹), protein (17.2g 100g⁻¹) and oil (45.7g 100g⁻¹). When compared to most other tree nuts (average 16.6g 100g⁻¹), cashew has a high total carbohydrate content (29.3g 100g⁻¹) (Duke, 1989).

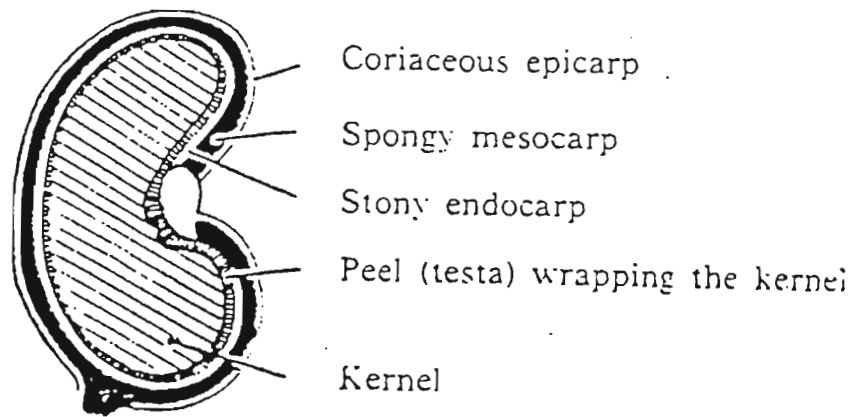


Fig. 2.6. Longitudinal section through a cashew nut (Agnoloni & Giuliani, 1977)

The yield of cashew is low owing to a small percentage of hermaphrodite flowers, low fruit set, heavy fruit drop, etc. (Hari Babu, 1982). Rao & Hassan (1957) reported only 3% fruit set, while Damodaran *et al.* (1966) observed 4 to 6% fruit set under Indian west coast conditions. Other researchers have found fruit set to range from 6 to 12% (Dasarathi, 1958; Misra, 1975).

The stages of formation and growth of cashew nut and apple were summarised by Agnoloni & Giuliani (1977) (Table 2.8). After pollination the ovary enlarges and within one week the young nut becomes visible to the eye. During the first two weeks the pericarp grows more rapidly than the embryo, but then the embryo grows more rapidly until it completely fills the shell cavity by the time the nut reaches its maximum size, five to seven weeks after fruit set (Fig. 2.7) After this the nut shrinks slightly (Table 2.9) the shell hardens and the green colour turns grey. When mature the nut is about 75% of its maximum size, mainly due to loss of water (Ohler, 1979).

Damodaran *et al.* (1966) showed that the size of the apple surpassed that of the nut only by the seventh week (Table 2.9). Roth (1974) also indicated that growth of the apple was much less than that of the nut during the first two thirds of the development stage, but then suddenly increased to twice the length of the nut in the final stage of growth.

Both in Brazil and India, nuts with a thin shell, not containing any CNSL, have been found. It is evident that the production of such nuts without CNSL might cause great changes in the processing industry, considerably reducing costs. There would be no danger of CNSL contamination of the kernel, and the kernel-to-whole-nut ratio would be much higher (Ohler, 1979).

Table 2.8. Mean development times for the cashew apple and nut (Agnoloni & Giuliani, 1977).

APPLE	TIME		NUT
	Progressive days	Interval days	
Fertilisation	0	0	Fertilisation
Formation and growth	5	5	Visible to naked eye
Formation and growth	20	15	Pink changes to green (soft consistency)
Formation and growth	35	15	Seed completely developed inside receptacle
Formation and growth	40	5	Maximum development (soft consistency)
Dimensions similar to nut's	45		
Maximum development	60	20	Maximum development (hard consistency)
Fully ripe	65	5	

Table 2.9. Development of cashew nut and apple during different stages of growth (Damodaran, Abraham & Alexander, 1966).

Weeks after fruit set	1	2	3	4	5	6	7	8
Nut								
length (mm)	8	21	29	34	35	33	29	26
% of max. length	22	59	83	97	100	94	84	75
width (mm)	6	12	17	20	21	20	18	17
% of max. width	28	57	79	98	100	95	87	81
Apple								
length (mm)	8	15	16	23	26	30	31	36
% of max. length	24	43	53	65	74	85	96	100
diameter at thickest part (mm)								
% of max. diameter	3	6	8	10	12	20	27	29
	10	19	26	35	41	69	91	100

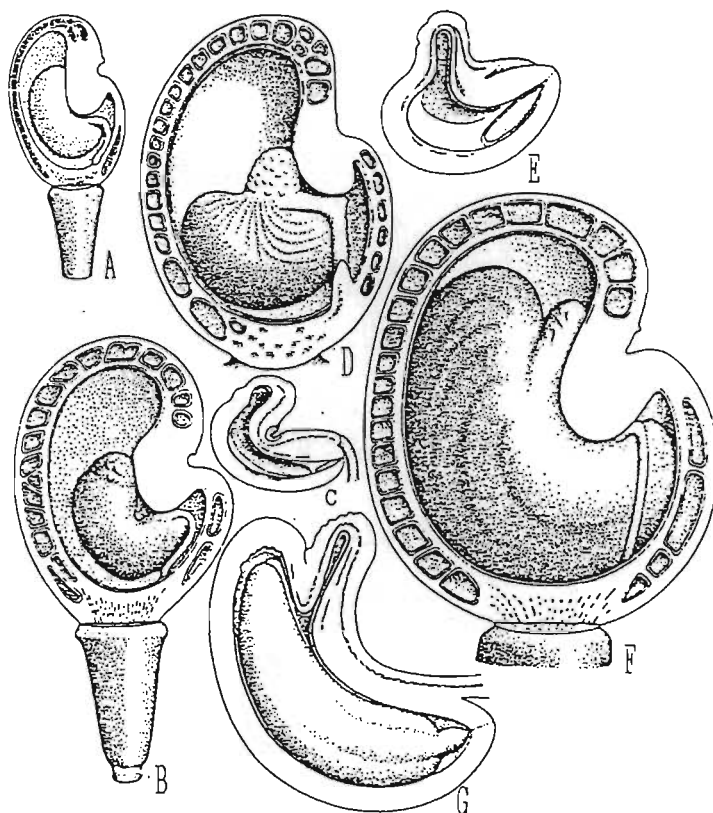


Fig. 2.7. Longitudinal section through developing fruits and kernels (x 2.5). A, B, D, and F: successive stages of the developing fruit. C, E, and G: sections of the developing kernel respectively from B, D, and F (Copeland, 1961).

2.2.2.2.2 Cashew Nut Shell Liquid (CNSL)

Cashew nut shell liquid is a rather viscous, oily or balsam-like substance with a relatively high density (1.013 g cm^{-3}). It is pale yellow to dark brown in colour, has a bitter taste and caustic properties, and when heated gives off pungent and choking fumes (Aggarwal, 1954). Cashew is one of the few vegetable sources of phenols. Fresh CNSL contains about 90% by mass of anacardic acid, a derivative of O-carboxyphenol that readily decarboxylates on heating and converts to anacardol or cardanol. The remaining 10% consists of cardal, a resorcinol (M-hydroxyphenol) derivative, and is mainly responsible for some vesicative action of the liquid. Related compounds are found in other plants of the family such as poison-ivy (*Rhus radicans*) and the Japanese lacquer tree (*R. vernicifera*) which are also in the family Anacardiaceae (Cornelius, 1966).

The CNSL content of the shell varies considerably. Cashew nuts from different regions in India were found to have CNSL contents ranging from 16.6 to 33% averaging from 20 to 25% of the whole nut mass (Murthy & Yadana, 1972; Ohler, 1979). Only about seven to 12% of total nut mass is usually recovered, but extraction efficiency can be increased to about 80% through expensive solvent extraction methods, if there is a large enough volume of shells to make it economical (Ohler, 1979).

People sensitive to poison-ivy develop skin sensitivity to CNSL. On contact, the liquid may cause swelling, rubefaction, vesication and even acute dermatitis (Watt & Breyer-Brandwijk, 1962). It is therefore very important that as little CNSL as possible contaminate the kernel during processing. Labourers in cashew processing units can suffer severe injuries if protective clothing is not worn.

There are over 200 patents for different industrial uses of CNSL (Ohler, 1979) and it is beyond the scope of this review to name them all. Because of its phenolic nature, CNSL has fungicidal and insecticidal properties as well as having excellent preservative effects on timber, paper, fishing nets, etc. (Agnoloni & Giuliani, 1977). When distilled and polymerised, CNSL is used in insulating varnishes, lacquers, inks, brake-shoe linings (the major use), acid- and alkali-resistant cement and tiles, heat and waterproof paints, heavy duty cutting and grinding discs, etc. (Ohler, 1979; Wait & Jamieson, 1983a).

With increased use of disc brakes, demand for CNSL will probably decrease, because mineral phenols can also be used in this type of brake. However, if the price of oil and its phenolic by-products increased, it can be expected that CNSL will be able to compete with mineral phenols, especially with the use of modern processing machinery with more efficient extraction capabilities (Wilson, 1975).

2.2.2.2.3 Cashew apple

The size of the apple can vary as much as that of the nut, and its shape even more so. The shape varies from almost round to elongated and scarcely resembling an apple. Often the apples are heart shaped (Fig. 2.1), hence the name *Anacardium*, meaning 'shaped like a heart'. In some cases the apple is not larger than the nut; in others it may be more than ten times as large. A ratio of 1:8 to 1:10 is commonly used. However in future the tendency will be to plant material selected for special purposes such as high nut yield, high nut plus apple yield, or high apple yield only, and any generalised ratios will have to be abolished (Ohler, 1979).

The very young apple is green or purple, turning green later. When ripe the apple becomes red or yellow, or some colour between these. The ripe apple is very juicy, somewhat fibrous and has a very thin skin that bruises easily. When fully ripe, the apple falls to the ground and can easily split making the pseudo-fruit unmarketable (Ohler, 1979).

The ripe apple contains about 85% juice which has a sugar content of about 10% and is quite astringent due to the high tannin content. Many chemical analyses have been made (Table 2.10), all of them differing (Ohler, 1979), which is not surprising considering the great variability among seedling cashew trees.

Bose (1964) observed that the growth of the apple was influenced by the presence of the nut. If the nut was removed at an early stage, the apple failed to grow and dried. Application of 2,4-D and 2,4,5-T stimulated the growth of the apple without the nut up to ripening.

Table 2.10. Composition of cashew apples according to three different analyses (CSIR, 1948 (1); Anon., 1969 (2); Haendler & Duverneuil, 1970 (3)).

	1	2	3
Moisture (g 100g ⁻¹)	86.1	85-90	87.9
Proteins	0.8	0.7-0.9	0.2
Fat	0.2	0.1	0.01
Carbohydrates	12.6	7.7-13	11.6
Fibre	0.6	---	---
Ash	0.3	0.19	0.2
		---	---
Ca (mg 100g ⁻¹)	0.2	4.2	10.0
P	19.0	6.1	10.0
Fe	0.4	0.7	0.2
Vitamin B ₁ (thiamine)	0.2	0-0.02	---
Vitamin B ₂ (riboflavin)	0.2	0.02	---
Niacin	0.5	0.13	---
Vitamin C	200	140-600	262
Vitamin A (i.u. 100g ⁻¹)	---	450	---

The cashew apple is a valuable fruit and it is a pity that consumption is so small. The vitamin-C content is several times as great as that of citrus fruits, which are widely appreciated and recommended in that respect. It is surprising that the consumption of cashew apples has not been more vigorously promoted, especially in tropical countries. With progressive and creative marketing the cashew apple would appeal to some sectors of the South African market, as a fresh fruit, juices, jams and/or even as alcoholic beverages. The marula (*Sclerocarya birrea*) is a good example of such marketing.

2.2.2.3 Manipulation of Flowering and Fruit Set

With the flowers of cashew being susceptible to fungal and insect attack it has become an important management principle to try to manipulate flower timing as well as to increase the ratio of hermaphrodite to male flowers. Fruit-set and retention should also be improved to increase yields.

2.2.2.3.1 Cultural Methods

2.2.2.3.1.1 Drought stress

Flowering is manipulated naturally by drought stress. Therefore one of the simplest management practices to control flowering would be to withhold irrigation until the panicles start to emerge. However, most cashew plantations have no irrigation system and rely totally on rainfall (Ohler, 1979).

2.2.2.3.1.2 Pruning

In Brazil, in experimental dwarf cashew orchards, shoots are cut off where flowering and/or fruiting has taken place. This soon induces new shoots; some of which differentiate flower buds and form flowers and fruit. This is repeated monthly so that cropping goes on all year round (Ascenso, 1988). Flowering is clearly manipulated in this way, but could only be applied where climatic conditions are fairly uniform throughout the year.

2.2.2.3.1.3 Girdling

Girdling (cincturing) has been used to induce artificial shoot dormancy and promote flowering in many species (Nakata, 1953) including mango (Furr & Cooper, 1946), citrus (Cohen, 1981) and other fruit trees, particularly when trees are growing vigorously (Cull & Paxton, 1983). In litchi (*Litchi chinensis* Sonn.) in Australia, dormancy was induced in all girdled branches (dormant and flushing), but flowering only improved when dormant branches were girdled (Menzel & Paxton, 1986). It was therefore important to girdle after the post-harvest flush is completed.

It has been reported that for girdling to be effective, the cut should remain "open" for two to three months (Menzel & Paxton, 1986). This time is a function of the time taken for the formation of callus bridges across the cut, renewing the connections between phloem bundles on either side of the girdle (Grierson *et al.*, 1982). On litchi a 3 mm wide girdle was found to be sufficient (Menzel & Simpson, 1987; Oosthuizen & Morse 1992).

The physiology of the effects of girdling is not well known, but a few concepts are well documented. There is a general rise in carbohydrate (CHO) levels above the girdle (Noel, 1970; de Villiers *et al.*, 1990) because the path of photosynthate movement to the roots has been physically cut off. This impedes translocation of sugars to the roots and may cause temporary root starvation, which may in turn decrease GA synthesis by the roots. Decreased shoot growth and increased yields may be explained in terms of this theory (Wallerstein *et al.*, 1973). Gibberellic acid has been shown to inhibit flower induction in mango (Pal & Ram, 1978) and in citrus (Monselise & Goren, 1978). The danger of damage to the tree due to detrimental effects on root development can be overcome by leaving about half the main branches un-girdled (Cohen, 1977). Only strong, healthy trees should be girdled because the stress imposed on weak trees could be detrimental in the long term, and may even be fatal (Young,

1977; Menzel & Simpson, 1987).

2.2.2.3.2 Chemical Methods

Chemical sprays to manipulate cashew flowering have been tried with varying success. The effect of growth regulators on the number of perfect flowers and on percentage fruit set has been studied in India. Pavithran & Ravindranathan (1976) sprayed gibberellic acid (GA_3) and indolyl-3-acetic acid (IAA) on the first five leaves of randomly selected twigs at weekly and fortnightly intervals. Spraying was started at the pre-initiation stage marked by rounded tips and was continued to the date of opening of the last flower of the panicle. GA_3 at 100 mg l^{-1} increased the total number of flowers per panicle by a factor of four. The duration of the first male phase was reduced by one third. The mixed phase was extended and the ratio of male to perfect flowers per panicle was reduced from 499:1 to 3,5:1, and during the mixed phase from 82:1 to 2,9:1. IAA reduced the duration of the flowering phase and total flowering time, but had no effect on sex ratio or on the number of flowers produced.

Murthy *et al.* (1975) sprayed cashew trees once or twice during flowering, with five different growth regulators, namely GA, IAA, naphthyl-1-acetic acid (NAA), 4-(indolyl-3)-butyric acid (IBA) and 2,4-dichlorophenoxy-acetic acid (2,4-D). NAA at 10 mg l^{-1} increased the percentage fruit set by 107%, 2,4-D at 10 mg l^{-1} by 57%, and IBA at 25 mg l^{-1} by 55%. The other treatments were less effective.

A large portion of the fruits which have set absciss for physiological reasons (Pillai & Pillai, 1975). Konhar & Arun Mech (1988) treated ten-year-old trees with several growth regulators three times at 15 day intervals. The highest percentage of fruit retention (25.8) was obtained with Nutron (triacontanol) at 500 mg l^{-1} followed by Ethrel (ethephon) at 50 mg l^{-1} (25.4% fruit retention) and Planofix (NAA) at 45 mg l^{-1} (22.8%). The control percentage was 7.3. Pappaiah *et al.* (1980) found that 50 mg l^{-1} Ethrel, sprayed at the time of new shoot growth, increased the percentage of perfect flowers from 5.1 to 9.0, and improved fruit set by 47% over unsprayed controls.

Potassium nitrate has been proven to be effective in mango flower induction in the tropics (Mosqueda Vazques & Santos de la Rosa, 1982) but no evidence of this on cashew was found. The use of KNO_3 to manipulate flowering could be related to N-containing compounds and stress physiology. According to Lovatt, Zheng & Hake (1988), "...any stress inhibiting the growth of a plant will result in the accumulation of ammonia (measured as the combined pool of NH_3/NH_4^*)". Rabe (1990) wrote that since stress is usually a requirement for flowering in many commercial fruit tree species, the intensity and timing of flowering could be controlled by exogenous application of chemicals which result in higher endogenous ammonia levels, thus "artificially" inducing stress. Promising results have been obtained by Lovatt *et al.* (1988) on citrus with foliar applied urea.

Galang & Lazo (1936) found that productivity of cashew was associated with leaf area and internode length. Dasarathi (1958) reported that trees with excessive growth and long internodes bore less than those with slow or medium vegetative growth. Paclobutrazol (PP333) was developed in the late 1970's as a growth retardant, and has been used successfully to control vegetative growth in many temperate fruit crops including apple, pear, peach and cherry (Quinlan, 1981; Raese & Burts, 1983; Edgerton, 1986; Looney & McKeller, 1987; Early & Martin, 1988), some ornamentals (Sterrett, 1985), and a few tropical and subtropical tree crops (Goldschmidt & Monselise, 1972) such as citrus (Bausher & Yelenosky, 1986; Harty & van Staden, 1988), mango (Kulkarni, 1988; Rowley, 1990b), macadamia (Kadman, Gaash & Erez, 1988), litchi (Menzel & Simpson, 1990; b; Rowley, 1990a), and avocado (Köhne, 1990; Wolstenholme, Whiley & Saranah, 1990). This chemical has been shown to cause a decrease in internode length, resulting in decreased tree vigour and the promotion of flowering in bearing trees, and precocious flowering in young grafts.

Paclobutrazol (β -[(4-chlorophenyl)methyl]- α (1,1-dimethylethyl)-1H-1,2,4,-triazole-1-ethanol) (Quinlan, 1981), is a member of a group of potent growth retardants termed sterol synthesis inhibitors or triazole derivatives. These compounds are known as kaurene oxidase inhibitors because they disrupt gibberellin synthesis by preventing the conversion of *ent*-kaurene to *ent*-kaurenoic acid, an integral step in gibberellin biosynthesis (Dalziel & Lawrence, 1984).

There is no reason to suspect that the use of this chemical to control flowering in cashew would fail. However, the move towards "green" products may necessitate the elimination of paclobutrazol as an option for cashew, especially if exporting to the EEC with its stringent standards regarding chemical residues in fruit and nuts and its fussy consumers (Menzel³, pers. comm., 1992).

It will not help much if artificial measures to increase hermaphrodite flowering and fruit set resulted in increased number of fruit but not in increased total harvested nut mass, or nut-plus-"apple" mass. After all the aim of such measures is to produce higher yields and/or quality of nuts or "apples" and if this were not achieved money and time would be wasted.

2.3 CROP IMPROVEMENT

2.3.1 Selection Criteria

The yield of cashew seedling trees varies enormously. There is also great diversity in tree shape and size, flowering patterns, quality of fruit, etc. (Agnoloni & Giuliani, 1977). The reason for this diversity stems from the highly heterozygous cashew plantings established from unselected or even selected, cross-pollinated seed (Ohler, 1979; Ascenso, 1986a; Wait & Jamieson, 1986; Roe, 1992). Selection

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and breeding research is a prerequisite to raise the level of cashew cultivation. Ohler (1979) reported that publications on such research are scarce and much of the work is still in its infancy. This statement is just as pertinent in the 1990's.

The first characteristic of importance to the farmer is the yield capacity of nuts, expressed in net returns, so this must be the most important selection criterion. Yields should be expressed in mass and quality of kernels, as these comprise by far the greatest part of the nut value. Kernel yield is the sum of two components; total nut mass produced, and kernel-to-whole-nut ratio. Kernel value can be influenced by kernel size, but flavour does not seem to vary much (Ohler, 1979).

2.3.1.1 Total Nut Yield

Total yield of nuts per tree, all conditions of soil, climate and plantation management being adequate, is the result of several genetically determined factors, including:

- growth and vigour of the tree;
- number of panicles produced;
- number of perfect flowers produced per panicle;
- average mass per nut;
- pest and diseases resistance; and
- extent of premature nut drop (Ohler, 1979; Wait & Jamieson, 1986).

Yields of mature trees vary from nil to about 100 kg nuts (in-shell) per annum. Average yields of plantations rarely exceed 1000 kg ha⁻¹, and are often less than 500 kg ha⁻¹ (Agnoloni & Giuliani, 1977; Ohler, 1979). Northwood (1966) recorded yields of a population of 1228 three-year old trees grown from unselected local seed at Nachingwea, Tanzania. The nut yields ranged from 0.36 to 6.78 kg tree⁻¹, with a mean of 2.6. The mean number of nuts produced per tree was 566, ranging from 65 to 1524. The mean number of nuts set per inflorescence for all trees was 4.8 ranging from 0.4 to 15.4. Finally, the mean mass per nut was 4.9, ranging from 3.1 to 8.0 g.

Correlation coefficients were calculated for the four sets of data, which gave an indication of some important yield factors. The number of nuts per tree and the mass of a single nut were highly correlated with yield ($r = 0.947$ and 0.351 respectively). The number of nuts per inflorescence was not associated with yield. As is commonly noted in the field, there was an inverse relationship between number of nuts per tree and mean nut mass ($r = -0.580$). Since the fruit set per inflorescence was, by itself, relatively unimportant it was deduced that the number of inflorescences produced per tree would be a major factor determining yield (Northwood, 1966).

Ohler (1979) argued that Northwood's (1966) conclusions may not be correct at higher yield levels. High yielding trees normally have more than one nut per inflorescence. Rao & Hassan (1957) found

in India, that the yield of a cashew tree was governed primarily by the number of perfect flowers produced, and that this characteristic was inherent to the tree, and not subject to manipulation by cultural practices. Pillai & Pillai (1975) found that nut drop due to defective physiology or metabolism was also a major contributor to low yields. Whether this factor is another inherent characteristic that overrules the characteristic of perfect flower production, should be looked into.

Northwood (1967), after considering the yields of the four best trees grown from unselected seed at Nachingwea, concluded that annual yields of about 2250 kg ha⁻¹ were possible for that region. He suggested that there may be a tendency for alternate bearing, which would possibly increase when trees grew older. Therefore it would be wise to monitor yields of apparently superior trees over at least six years, longer if possible, before using them in a breeding programme.

Chacko *et al.* (1990) reported that, under first world conditions, as they prevail in Australia, yields of 4 to 4.5 t ha⁻¹ would have to be produced in order to be economically competitive. This would be achieved by selecting the most suitable sites, the use of supplementary irrigation, clonally propagated, high-yielding selections, close planting, and optimal management. The Australian breeding programme is utilising parent trees having upright growth habit and intensive branching systems, aimed at generating compact trees with a large number of terminals, capable of producing medium-sized nuts (8 to 10 g), with small apples bearing in bunches of five to 10 nuts. These genetically-tailored 'super trees' producing in excess of 30 kg tree⁻¹, could be planted at 8 x 5 m, and produce 5 to 7 t NIS ha⁻¹. This is possibly the greatest potential yield for commercial cashew enterprises.

From the yield figures above, there is great scope for production improvement through the use of selected plant material from existing cashew plantations, and by breeding super trees. Studies would be recommended on possibilities of early selection in the nursery.

2.3.1.2 Kernel-to-Nut Ratio

Not much data are available on the kernel-to-nut ratio. Rocchetti & Moselle (1967) analysed a sample of Tanzanian nuts, finding a mean kernel percentage of 29, varying from 23 to 43. Once plantations have been established from vegetatively propagated material, a much higher general average kernel percentage may be achieved than from a heterogenous plantation. Ohler (1979) found that kernel percentages of six trees in Brazil ranged from 19 to almost 32. The largest nuts, weighing 15 to 16 g had the lowest ratio, followed by the smallest nut of 1.2g with a kernel percentage of 24.4. Medium sized nuts (5.3 and 7.4 g) had ratios 30.4 and 29.9 respectively. This indicated that medium-sized nuts in general give the highest kernel yields.

Turner (1956) and Auckland (1961) investigated nuts for planting purposes and also found that large

seeds were of lower density than medium sized ones. In general trees producing medium sized nuts are the highest nut yielders, and it seems that the highest total kernel yield is to be found in this group.

2.3.1.3 Consistency of Nut Size

Selection of trees should be aimed at improving uniformity of nuts, since good decortication in industrial processing is linked to size and shape of nuts (Agnoloni & Giuliani, 1977). There have been no indications that the maxima and minima of nut masses are influenced by climate. Trees which produced a large number of nuts had small nuts unsuitable for the cashew trade (Northwood, 1966). However this could have been due to water and/or nutritional deficiencies and not because of the number of nuts produced by the tree.

2.3.1.4 Thin Shelled Nuts

It is obvious that nuts with thin shells have a higher kernel percentage, yet breeding for thin-shelled nuts is virtually non-existent. Not only would the kernel-to-nut ratio be improved, but the method of processing might be simplified, thus reducing processing costs. Processing of thin-shelled nuts would yield more kernels without additional costs of labour and machinery and consequently the market position would be improved. Decreases in processing costs could allow for price increases to the growers. Thin shelled nuts have been found in India and Brazil (Ohler, 1979).

2.3.1.5 Canopy Growth and Shape

Nambiar (1977) suggested that critical comparison of photosynthesis in cashew plants with different canopies was desirable to determine the optimum plant canopy with respect to high yield. However Wolstenholme (1990) noted that it was not only the photosynthetic efficiency but also the photosynthate partitioning that determined yields of perennial trees. Studies of this nature are difficult and there are easier, more visual methods of selection.

Being peripheral bearers, fruit production declines dramatically on branches that intermingle with those of adjacent trees. According to Morton (1970) trees exhibiting sprawling growth produced only a tangled mass of dead and bare branches. Trees with a more erect growth habit flowered and yielded much more than those with a sprawling growth habit. Erect trees could also be grown at closer spacing, thus increasing the bearing surface per hectare. When "apples" are to be harvested before falling, the lower growing spreading trees would be preferred for easy harvesting. If few or no apples are required, the tall trees would supply sufficient apples on their lower branches (Ohler, 1979). It makes sense to find such trees with high yields.

2.3.1.6 Dwarf Types

Cashew trees which are much smaller than normal have been selected in both India (Ohler, 1979) and

north-eastern Brazil (Ascenso, 1986b; 1988). These probably arose as mutations. Records showed individual tree variation for several characters such as earliness of bearing, tree size, yield, and nut quality. Brazilian researchers were thus able to select a few outstanding trees which were cloned and are being tested in clonal trials (Ascenso, 1986b; 1988).

The dwarf clones exhibited two major advantages over common cashew selections, viz. the smaller tree size, as assessed by tree height, trunk girth and canopy span, and secondly, earliness of bearing. Nut quality was quite acceptable, nut size was consistently higher than 6.0 g and kernel content similar to or higher than that of common cashew selections. Individual tree yields may have been somewhat lower than those of high-yielding common cashew selections, but high density plantings of selected high-yielding dwarf types were considered to have the potential of yielding several times more per hectare than standard sized cashew trees (Ascenso, 1986b; 1988).

2.3.1.7 Precocity and Early Seasonal Flowering

Selection of cashews for precocity would give advantages only if such trees continued to yield as well as, or higher than, the other trees in later years. Early seasonal flowering may be advantageous where the dry season is short. However this may not always be consistent and observations of trees over several years would be required for selection on this aspect (Ohler, 1979).

Some trees have a relatively long flowering period and nuts produced on late flowers may ripen in the next rainy season and become spoiled due to humid conditions (Ohler, 1979). As previously mentioned this is a major problem encountered in Maputaland where flowering starts during August and early September, at the time when the spring rains start falling, and persists for eight months through spring and summer. Nambiar (1974) suggested that breeding and selection for reducing the length of the flowering phase, i.e. for more strongly synchronised flowering, deserved emphasis to avoid fruit wastage and to simplify management of the crop.

2.3.1.8 Pest and Disease Tolerance or Resistance

The most destructive diseases of cashews in East and southern Africa, powdery mildew and anthracnose (Brown *et al.*, 1984), will require vast amounts of expensive fungicides if they are to be controlled effectively. Fungicides are also a relatively short term solution as fungal resistance to the fungicides could be evolved. The long term solution would be to select for disease tolerance. 'AC4', a cashew clone selected in Tanzania, is said to have tolerance to powdery mildew, while being a consistent high nut and "apple" yielder, with high kernel percentage (26 to 28%) and large kernels (9.5g) (Conticini & Partel, 1983). The genes in this clone would obviously be very useful in a breeding programme.

2.3.2 Breeding

Practically no information is available on the genetics of different characters in cashew, though there have been attempts to correlate yield with a number of characteristics (growth habit, flower intensity, sex ratios, fruit per panicle, panicles per tree, etc.) (Nambiar & Thankamma Pillai, 1985). The first step of a breeding programme is the identification of the best parent trees. This may be a costly and laborious task when many of the trees are found in smallholders' groves or are growing semi-wild. Vegetative propagation of such trees and observation of the clone at a research station would save much time for those making the selection, but it would be a longer time before results become available (Ohler, 1979).

The characteristics selected for should be present in high frequency and should have high heritability. The heritability of desirable characteristics (eg. medium length of internode, intensive branching, intensive flowering, a high proportion of bisexual flowers, short flowering phase, nut size, etc.) and these and other morphological characteristics must be correlated with yield. It has been established that nut yield from a tree is proportional to the number of fruits set, and the total number of flowering shoots, per unit area (Nambiar & Thankamma Pillai, 1985). Correlating seedling characteristics with subsequent yield would be an added advantage in selection (Nambiar, 1977). An example is that nut mass has a positive correlation with the height of seedlings and number of leaves, and negative correlation with girth and internodal length (Anon., 1978).

Trials by Damodaran (1975) indicated that hybrid vigour is displayed by cashew (Table 2.11). If the vegetatively propagated progenies of the F-1 hybrids also possess this hybrid vigour, good use could be made of it in establishing high yielding plantations (Ohler, 1979).

Table 2.11. Yield data for selfed, open-pollinated and hybrid cashew trees (adapted from Nambiar & Thankamma Pillai, 1985).

Treatments	Mean	yield	of	nuts	(kg tree ⁻¹)
	1971/72	1972/73		1973/74	1974/75
Selfed trees	0.550	0.627		0.286	1.298
Hybrids	1.263	2.391		1.072	2.450
Open pollinated	0.500	1.116		0.461	1.547

The hybridisation techniques consisted of clipping all the staminate flowers in a panicle, emasculating either all the stamens or the single functional stamen from the perfect flowers and bagging with butter paper. Anthers from selected trees were collected the following morning, the pollen dusted on the stigmatic surface of the emasculated flowers by a brush, and the butter paper replaced (Nambiar & Thankamma Pillai, 1985).

Most plant breeding programmes follow two approaches to develop cultivars with high yield potential; the "selection for yield" and "defect elimination" approach which are self explanatory terms. A newer approach involves breeding of ideotypes with a view to tailoring new selections of cashew for different environments (Nambiar, 1977). It would seem that cashew ideotypes should have intensive branching with medium internode length, more flowering laterals, a short flowering phase, high percentage of bisexual flowers, high fruit set, medium nuts with high shelling percentage, disease tolerance, and kernels with high protein content. Cashew breeders should try to select or breed cultivars with high adaptability to varying ecophysiological conditions (Nambiar, 1977).

CHAPTER 3 : GENERAL MATERIALS AND METHODS

3.1 TREE CULTURE

3.1.1 *Glasshouse trials*

Cashew seed (J1/89) was selected from a high yielding tree (J1) in a c. 25 year old cashew orchard near Gazini in northern Maputaland in 1989. These were germinated in a 1:1 mixture of organic soil and sand in 10 l pots at Mosi Estate in February 1989 and delivered to the University of Natal, in October 1989, when they were about 30 to 50 cm tall. The seedlings were fertilised with 20g superphosphate (10.5% P) at planting, then 10g 2:3:2 (30) after two, seven, and 12 months to get maximum growth. Pots were irrigated with 5 mm of water twice a day for the first three months, after which this was reduced to once a day and eventually to once a week in the nursery. Fungicides and insecticides were applied regularly to control pathogens and insect pests.

The trees were repotted into 20 l black polyethylene nursery bags using river sand as a medium in January 1990, making sure that the roots were disturbed as little as possible. These trees were kept under optimum growing conditions in a glasshouse, irrigated twice a week until run-through and fertilised with 15g 2:3:2 (30) every three months until the experimental work started. Once trials commenced irrigation was applied daily by drippers.

3.1.2 *Field trials*

Three-year old (in 1990), dry-land, seedling trees growing in organic sands overlying gleyed impervious subsoils (Champagne Form, Mposa Series) (Appendix IV) in a swampy area were made available for a chemical spray trial at Mosi Estate, Phelandaba, Maputaland (north eastern Natal/KwaZulu). Irrigated seedling cashew trees of the same age, growing in sandy soils (Regic sands - Fernwood Form, Fernwood/Warrington Series) (Appendix IV) were made available by Makatini Research Station, near Jozini, for a study of winter drought stress on cashews.

3.2 LABORATORY TECHNIQUES

3.2.1 *Tissue Starch Determination*

Starch determination was done using an enzyme colorimetric technique adapted firstly by Graham (1991) and later by Kaiser (1993) from the techniques described by Trinder (1969), Bauminger (1974), Gallati (1977) and Rasmussen & Henry (1990). Starch is hydrolysed by using a heat stable alpha-amylase during gelatinisation in near-boiling water. This is then converted to glucose with amyloglucosidase. The amount of glucose can be quantified using a glucose-specific enzymic oxidase/peroxidase reaction with a 4-amino antipyrine chromogen. Starch can then be quantified from a standard curve and calculated on a percentage dry mass basis.

Glucose is released by hydrolysis of the α -(1-4)-linkages of dextrin from the non-reducing end of the starch molecule, using α -1-4-glucosidase. Alpha-1-6 glucosidase hydrolyses the α -(1-6)-D-glucosidic

linkages in amylopectin (Duffus & Duffus, 1984). In this way starch can be degraded to its monomer, glucose. A determination of percentage glucose, on a mass glucose per unit mass dry plant material basis, can therefore be considered a direct indication of starch content on a similar % basis (Graham, 1991).

The two enzymes used for starch degradation in this technique were Termamyl[®] 1 (Novo[®] 120L) during starch gelatinization and amyloglucosidase (Novo[®] 200L) for the complete breakdown of starch to glucose. Termamyl[®] (NovoSM 120L) is a liquid enzyme preparation with a heat-stable α -amylase produced by a strain of *Bacillus licheniformis*. It has an activity of 120 KNU g⁻¹. One kilo novo[®] unit (1 KNU) is the amount of enzyme which breaks down 5.26 g starch (Merck, Amylum Soluble Erg. b. 6, Batch 9947275) per hour at Novo[®]'s standard method of determination of α -amylase (Novo[®] AF 9) (Graham 1991).

Novo[®] (200L) amyloglucosidase, an industrial enzyme, was chosen instead of that outlined by Rasmussen & Henry (1990) because it was cheaper, more readily available and of higher activity than those produced specifically for laboratory use. It was found to be a satisfactory laboratory enzyme which did not interfere with the colour absorbtion wavelengths employed in glucose quantification and stored well (over a year at 4°C).

Novo[®] (200L) is an exo-amylase (gluco-amylase) produced by submerged fermentation of a strain of *Aspergillus niger*. The enzyme hydrolyses 1,4- as well as 1,6- α linkages in starch hydrolysates. The rate of hydrolysis depends on the chain length: maltotriose, and in particular maltose being hydrolysed at a lower rate than other oligosaccharides. Amyloglucosidase (Novo[®] 200L) has an activity of 200 AGU ml⁻¹. One Novo[®] amyloglucosidase unit (1 AGU) is the amount of enzyme which hydrolyses 1 μ mol of maltose min⁻¹ under the reaction conditions used in Novo[®]'s standard assay procedure (Novo[®] AF 22) (Graham, 1991).

3.2.1.1 Method

3.2.1.1.1 Apparatus

Apparatus used in this technique included:

- Labotec Term-O-Mat[®] forced draught oven,
- Microhammer mill built by University of Natal Science Workshop,
- Beckman DU-65[®] spectrophotometer,
- Heidolph vortexer,
- Refrigerator,

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- 2 l volumetric flask,
- 250 ml beakers, and
- 10 ml test tubes.

3.2.1.1.2 Reagents

3.2.1.1.2.1 Acetate buffer

Measure out 5.72 ml of 99.8 % acetic acid, add 167 mg CaCl_2 , add NaOH (10 to 12 pellets in 20 ml water) until pH = 5 and then make up to 1 l with distilled water.

3.2.1.1.2.2 Glucose oxidase colour solution

Dissolve:

1. 24.8 g disodium hydrogen orthophosphate ($\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$; 358.15 g mol^{-1}) (AR grade),
2. 12.4 g sodium dihydrogen orthophosphate ($\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$; 156.01 g mol^{-1}) (AR grade),
3. 4.0 g benzoic acid ($\text{C}_7\text{H}_6\text{O}_2$) (GPR grade) dispersed in a small volume of ethanol,
4. 0.2 g 4-amino-antipyrine (Sigma®A-4382),
5. 3.0 g p-hydroxybenzoic acid (Sigma®H-5376),
6. 0.04 g glucose oxidase (Sigma®G-2133), and
7. 0.01 g peroxidase (Sigma®P-8375),

in about 1800 ml of distilled water in a 2 l volumetric flask, then make up to 2 l. Store at 4 °C in the dark. Remove from the refrigerator immediately before use. This reagent may be kept in a refrigerator for extended periods, but should be discarded when absorbance readings increase dramatically.

3.2.1.1.2.3 Glucose standard solution

Add 1 ml of 1 mg ml^{-1} glucose standard solution to 9 ml distilled water (gives 10 ml of 100 $\mu\text{g ml}^{-1}$ dilution) and vortex. This is used to develop a glucose standard curve to the following set of volumes.

From this pipette out the following:

Volume of glucose dilution (100 $\mu\text{g ml}^{-1}$) (μl)	Colour solution ml	Glucose concentration (g 5ml^{-1})
100	4.900	0.010
200	4.800	0.020
300	4.700	0.030
400	4.600	0.040
500	4.500	0.050
800	4.200	0.080
100	4.900	0.100
120	4.880	0.120
150	4.850	0.150
180	4.820	0.180

3.2.1.1.3 Procedure

3.2.1.1.3.1 Tissue preparation

1. Mill forced draught oven or vacuum oven dried tissue.
2. Weigh approximately 0.05 g of sample into a 10 ml test-tube.
3. Add 2.5 ml 80 % ethanol.
4. Seal the test tubes with rubber bungs.
5. Extract for 30 mins in a waterbath at 80°C.
6. Centrifuge for 10 mins (3 000 rpm).
7. Decant the supernatant containing the sugars.
8. Repeat steps 3 to 7.
9. The pellet may now be stored frozen for later analysis if necessary.

3.2.1.1.3.2 Starch digestion

1. Add 2.5 ml acetate buffer and 50 µl Termamy[®] and vortex.
2. Seal the test tubes.
3. Incubate for 30 mins in a hot (90°C) water bath.
4. Remove the tubes and allow them to cool to room temperature.
5. Add 50 µl amyloglucosidase (Novo[®] 200L) and vortex.
6. Seal the test tubes.
7. Incubate at 60°C for approximately 20 h.
8. Centrifuge for 10 mins (3000 rpm).

3.2.1.1.3.3 Colour reaction

1. Transfer 100 µl of the supernatant, after centrifuging, into a test-tube and then proceed with step 2.

Note: If high starch concentrations are expected, 0.5 ml supernatant may be diluted to 10 ml and then 0.2 ml of the diluted supernatant transferred into a test-tube for glucose analysis. This dilution ratio can be varied according to the expected starch concentration. The concentration of dry material up to this stage was

$$\frac{0.05 \text{ g}}{(2.5 + 2(50 \mu\text{l}))} \text{ g ml}^{-1}.$$

From this 100 µl was subsampled; or 0.5 ml was sub-sampled and diluted with 10 ml of distilled water, and out of this a further 0.2 ml sub-sampled. This is then treated and analyzed for colour development. Therefore, there is

$$\frac{(2.5 + 2(0.05))}{0.1}$$

= 26 times more dry matter in that test-tube before any sub-sampling than was used for the colour development and detection. Consequently, the amount of starch (glucose) that is detected must be multiplied by this factor in the end calculation so that %

starch can be calculated on a mass glucose per mass dry matter basis. Hence by changing the dilution ratio, one merely changes the multiplication factor in the end calculation of % starch.

2. Make up the transferred supernatant to 5 ml using glucose oxidase colour solution.
3. Prepare a glucose standard curve. (As in 3.2.2.2.3).
4. Seal the test tubes and incubate in a water bath for 15 mins at 40°C.
5. Allow to stand at room temperature for a further 60 mins.
6. Read absorbances at 505 nm.

3.2.1.1.3.4 Calculation

$$\% \text{ STARCH} = \frac{\text{MASS} \times \text{DIL} \times \text{K}}{\text{W}} \times 100$$

Where: MASS = Mass (g) of glucose sub-sampled for colour development.

DIL = Dilution factor constant.

K = Water of hydrolysis constant = 0.9.

W = Total dry mass (g) of sample.

3.2.2 Leaf Ammonium Determination

According to Lovatt *et al.* (1988), "any stress inhibiting the growth of a plant will result in the accumulation of ammonia (measured as the combined pool of $\text{NH}_3/\text{NH}_4^+$) to an extent directly correlated with the severity or duration of the stress". In order to test this hypothesis, leaf samples were taken from cashew trees which were stressed in a number of ways and analysed for **free ammonia/ammonium** content. The following procedures were followed:

3.2.2.1 Salicylate Method

The first technique attempted was a colorimetric technique adapted from Nelson (1983), but there was interference of some type with this technique. Even though the standards achieved the expected colour (emerald green), the colour which appeared in the samples was a murky brown and negative readings resulted at the absorbance wavelength. The technique is outlined as follows:

3.2.2.1.1 Sample Preparation

The youngest, fully expanded, green leaves were sampled, washed in detergent, rinsed in water and dried at 70°C to constant mass. Once dried the samples were milled and stored in plastic packets in a freezer (-15 to -20°C) until analysis.

3.2.2.1.2 Extraction

1. Add 50ml 1M KCl to \pm 0,5g dry sample material.
2. Shake for 30 mins.
3. Filter through Whatman No. 42 filter paper.
4. Pipette 2,5ml 1M KCl into a 50ml test tube.
5. Add 2,5ml extract and shake gently.

3.2.2.1.3 Complex-formation

1. Pipette 4ml Na salicylate-nitroprusside solution into extract and mix well (swirl gently).
2. Add 13ml distilled water and mix well (swirl gently).
3. Pipette 2ml buffer solution and mix well (swirl gently).
4. Incubate in waterbath at 37°C for 30 mins.

3.2.2.1.4 Absorbance

Allow solution to cool and measure the absorbance at 667nm spectrophotometrically (within 4 h).

3.2.2.1.5 Standards

1. Prepare a range of standard solutions: Add 0, 1, 2, 3, 4, 5, 8, 10, 11, and 12ml of a standard $(\text{NH}_4)_2\text{SO}_4$ solution in water ($2\mu\text{g NH}_4\text{-N per ml}$) into test tubes (50ml) each containing 5ml of a 1M KCl solution.
2. Na salicylate and buffer solution are added in the same way as with samples.
3. Make to 24ml total by adding distilled water e.g.

Standard solution ($2\mu\text{g NH}_4\text{-N per ml}$)	0	1	2	3	4	etc
Distilled water	13	12	11	10	9	

4. Place in waterbath together with samples and determine absorbance at 667nm as in (3) above.
5. Plot known $\mu\text{g NH}_4\text{-N per 24ml solution}$ (X-axis) against the absorbance (Y-axis) to set up a standard curve.

3.2.2.1.6 Calculation

$$\text{NH}_4\text{-N per g dry sample} = \frac{[\text{Value ex standard curve } (\mu\text{g})] \times [\text{Extraction volume}]}{[\text{Total dry mass (g)}] \times [\text{ml extract in reaction mix}]}$$

$$= \mu\text{g NH}_4\text{-N g}^{-1} \text{ dry mass}$$

3.2.2.1.7 Reagents

1. 1M KCL: Dissolve 74,56g KCL in 1 l distilled water.
2. Sodium salicylate nitroprusside: Dissolve 7,813g $\text{NaC}_7\text{H}_5\text{O}_3$ and 106,25mg $\text{Na}_2\text{Fe}(\text{CN})_5\text{NO}_2\text{H}_2\text{O}$ in 80ml distilled water and make to 100ml.
3. Buffer solution: Dissolve 2,96g NaOH and 7,46g $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$ in 60ml distilled water. Add 14ml NaOCl solution (3,5% m/v). Adjust buffer solution to pH = 13 and dilute to 100ml.
4. Standard ammonium solution: Prepare a stock solution by dissolving 0,9346 g $(\text{NH}_4)_2\text{SO}_4$ in 1 l distilled water. The resulting concentration is $200\mu\text{g NH}_4\text{-N ml}^{-1}$. To prepare a $2\mu\text{g NH}_4\text{-N ml}^{-1}$ standard solution dilute 10 ml of the stock solution to 1 l with distilled water.

3.2.2.2 Semi-automated Method for Determination of Nitrogen ($\text{NH}_3/\text{NH}_4^+$) in Plant Tissue using a Technicon AutoAnalyzer^R

Because of the interference obtained in the above salicylate method, an Auto-analysis procedure was tried with greater success.

The samples were prepared and extracted in the same manner as the Salicylate method above, and then run through a Technicon AutoAnalyzer^R using the method reported by Hambleton (1977).

3.2.2.2.1 Reagents

1. Sampler wash solution (6 % H_2SO_4): Add 60 ml H_2SO_4 to 800 ml H_2O . Cool, make up to 1 l with H_2O and mix. This reagent contains no wetting agent.
2. Phosphate-tartrate buffer solution - pH 14.0: Dissolve 50 g sodium potassium tartrate and 26.8 g $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$ in 600 ml H_2O . Add 54 g NaOH and dissolve. Add 1 ml Brij-35 (Wetting agent - Technicon Instruments Corp.), dilute to 1 l with H_2O and mix.
3. Sodium chloride - sulphuric acid solution: Dissolve 200 g NaCl in H_2O in a 2 l volumetric flask. Add 15ml H_2SO_4 and 2 ml Brij-35. Dilute to volume with H_2O and mix.
4. Sodium hypochlorite solution: Dilute 6 ml commercial bleach solution (5.25 % available Cl_2) to 100 ml H_2O and mix. Prepare fresh daily.

5. Sodium salicylate Nitroprusside solution: Dissolve 150 g $\text{NaC}_7\text{H}_5\text{O}_3$ and 0.3g $\text{Na}_2\text{Fe}(\text{CN})_5\text{NO}_2\cdot\text{H}_2\text{O}$ in 600 ml distilled water. Add 1 ml Brij-35, make to 1 l and mix.

3.2.2.2.2 Standard solutions

1. Prepare a stock solution by dissolving 0,9346g $(\text{NH}_4)_2\text{SO}_4$ in 1 l of 1 M KCl. KCl is used in the standards because of the use of KCl as a solvent in the ammonium extraction procedure. This gives a concentration of $200\mu\text{g NH}_4\text{-N ml}^{-1}$. To prepare a $0.2\mu\text{g NH}_4\text{-N ml}^{-1}$ standard solution dilute 1ml of the stock solution to 1 l with distilled water.
2. Prepare a series of standards in the following way:

Standard solution ($0.2 \mu\text{g NH}_4\text{-N ml}^{-1}$)	0	0.25	0.5	0.75	1.50	2.50	4.00	5.00
1 M KCl (ml)	100	99.75	99.50	99.25	98.5	97.5	96.0	95.0
NH_4 concentration ($\mu\text{g l}^{-1}$)	0	0.5	1.0	1.5	3.0	5.0	8.0	10.0

3. These solutions are then fed into the AutoAnalyzer[®] every 10 to 20 samples to get a standard curve.

3.2.2.2.3 Sequence of events in the Technicon AutoAnalyzer[®] (Fig. 3.1).

1. The extracted sample is sipped up by the AutoAnalyzer sipper and combined with the $\text{H}_2\text{SO}_4/\text{NaCl}$ solution and air and mixed.
2. The mixture passes through a dialyser and the buffer is then added.
3. After further mixing the salicylate reagent is introduced and mixed in.
4. Sodium hypochlorite solution is received and mixed.
5. The colour development takes place at 37°C before being measured in the colorimeter at 660 nm.
6. The curves are recorded and sample $\text{NH}_3/\text{NH}_4^+$ concentration can be read off the standard curve.

3.2.2.2.4 Calculations

$$\mu\text{g NH}_4\text{-N g}^{-1} \text{ sample} = \frac{[\text{Value ex standard curve } (\mu\text{g})] \times [\text{Extraction volume}]}{[\text{Total dry mass (g)}] \times [\text{ml extract in reaction mix}]}$$

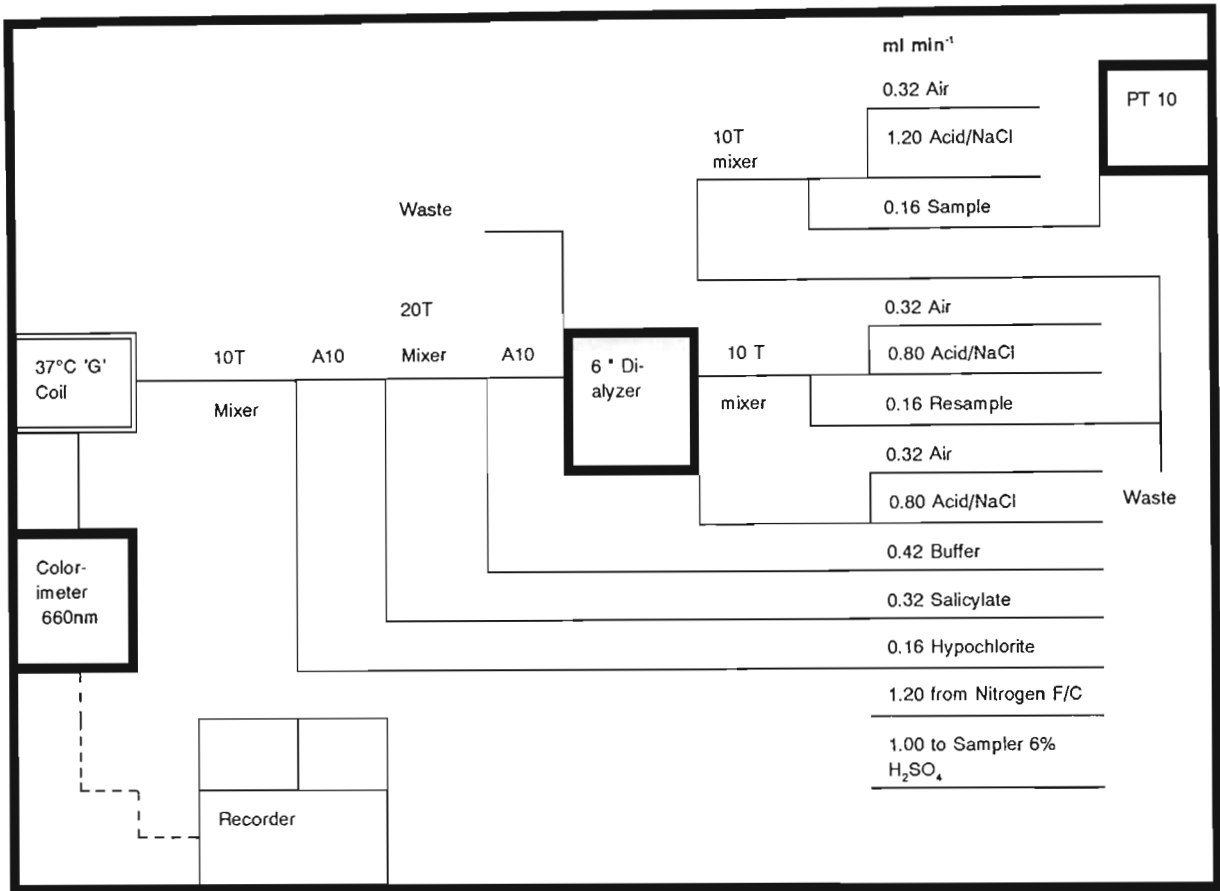


Fig. 3.1. Flow diagram of the AutoAnalyzer^R process for NH₃ determination (Adapted from Hambleton, 1977).

3.3 EXPERIMENTAL DESIGN AND ANALYSIS

Experiments were set up in the form of factorial or randomised complete blocks designs. In one case where two temperature regimes were necessary, the trial required two glasshouses, and therefore treatment effects may have been coupled with some site differences.

Statistical analysis was by standard analysis of variance and regression analysis procedures, using Genstat 5, MSTATC, or Statgraphics computer software.

3.4 WAX EMBEDDING AND MICROSCOPY

Leaves were sampled from glasshouse and field trials, and microscopic cross-sections were made to determine any differences in anatomy between leaves in the glasshouse and in the field. The leaves were treated according to a protocol supplied by the Department of Grassland Science, UNP, in the following way:

3.4.1 Sampling

Leaves approximately 4 to 6 months old were removed from the tree, immediately cut into cross-

sectional strips c. 20 mm long and 5 mm wide.

3.4.2 Fixation

Fix in a FAA (Formalin-acetic acid-alcohol) for a minimum of 24 h. Ingredients for FAA consisted of:

96% ethanol	50 ml
Acetic acid	5 ml
37 % formaldehyde	10 ml
distilled water	35 ml

3.4.3 Dehydration

Dehydrate through a graded tertiary-butanol series as follows:

<u>Solution</u>	<u>Minimum Time (h)</u>	<u>Temperature</u>
Water : ethanol : tertiary-butanol		
1. 45:45:10	1	Room Temperature
2. 30:50:20:	12	±20°C
3. 15:50:35	1	
4. 15:40:55	1	
5. 0:25:75	1	
6. 0:0:100	2	40°C
7. 0:0:100	18	40°C

3.4.4 Infiltration

Infiltrate the dehydrated tissue with wax as follows:

<u>Solution</u>	<u>Minimum Time (h)</u>	<u>Temperature (°C)</u>
1. Tertiary butanol: liquid paraffin (50:50)	24	40
2. Liquid paraffin	12	40
3. Liquid paraffin and a few wax pellets	12	40
4. Liquid paraffin and wax pellets in an open vial	24	60
5. Pure molten wax	48	60

Once the plant material is completely impregnated with wax, embed each specimen in pure wax and refrigerate for approximately 2 h. The next stage is to trim the blocks in which the specimens are embedded such that sections of the required thickness and orientation can be obtained. Once sections have been cut they have to be mounted on glass microscope slides which have been coated with an adhesive such as Haupt's adhesive or chrome-gelatin-alum adhesive. A drop of 3%

FAA is then placed on each slide. Ribbons of sections are floated onto the FAA after which they are stretched and dried at 40 C.

3.4.5. *Staining of Wax Sections With Safranin and Fast Green*

Prior to staining, dewax sections in two 3 min rinses of xylene. Then proceed as follows:

xylene/alcohol	1 min
95% alcohol	30 secs
70% alcohol	30 secs
Safranin stain	20 mins
95% alcohol	30 secs
Absolute alcohol	1 min
Absolute alcohol	1 min
50% absolute alcohol : 50% xylene	1 min
Fast green	few secs (straight in and out)
50% xylene : 50% alcohol	30 secs
xylene	1 min

The section is then mounted in Canada balsam or other appropriate mountant. The stain colours can then be interpreted as:

cellulose	blue green
cytoplasm	blue green
lignin	red
suberin	red/orange
cutin	green
DNA	red/purple
tannins	red-brown

3.5 PHENOLOGICAL RATINGS (FIELD TRIALS)

Flowering, flushing and unopened flower buds were rated as phenological observations. Trees were viewed from the north, as the southern sides of the trees were not reliable indicators of the phenological events (most flowering occurred on the northern side of the cashew trees in Maputaland). Ten to 20 branches were selected at random and the percentage of the branches displaying the phenological event being rated was determined and recorded.

CHAPTER 4. GLASSHOUSE STUDY: EFFECT OF DROUGHT AND COLD STRESS ON GROWTH OF CASHEW SEEDLINGS.

4.1 INTRODUCTION

The cashew is a monsoon tropical evergreen tree and thrives at high temperatures, often exceeding 40°C. Mean monthly temperatures around 27°C are optimum, with absolute minima and maxima being about 5°C and 45°C respectively (Ohler, 1979). Flowering normally occurs after the growth flush at the end of the rainy season but its timing and duration are strongly influenced by temperature (Wait & Jamieson, 1986). Preliminary observations in Maputaland showed that flowering coincides with peak rainfall (September to December), and indicated a water deficit stress period of one month to six weeks to induce flowering in cashews (Staples, undated).

The area proposed for cashew development in Maputaland is situated at the tropical/subtropical boundary and experiences regular winter cool periods, which is vastly different from the reported preference of cashew for "high but above all constant temperatures" (Agnoloni & Giuliani, 1977). Cashews, particularly mature trees, are known to be able to tolerate sporadic cool periods, but commercial cultivation is not recommended in areas where the mean daily minimum drops below 15 to 20°C (Ohler, 1979). In Maputaland the average daily minima drop below 15°C for 4 to 5 months annually. There is also a shallow water table, which may prevent the required drought stress period for satisfactory synchronised cashew flowering to occur (Ohler, 1979).

In this trial an attempt was made to determine the extent to which different durations of cold treatment could replace, or reinforce, the drought-stress induced flowering stimulus in cashews. The main objectives were to attempt to manipulate flowering to occur at the most suitable time (before the rainy period), as well as to synchronise flowering into a shorter period.

4.2 MATERIALS AND METHODS

4.2.1 *Experimental Design and Description of Treatments*

Eighty eighteen-month old seed propagated cashew trees received from Mosi Estate, and prepared for the experiment as described in section 3.1.1, were used in this trial. In order to study the effects of both drought and low temperatures, a randomised complete blocks factorial design (Appendix V) was utilised. Four levels of each factor were used in all treatment combinations (Table 4.1), a total of 16 treatments. Plots consisted of single trees and these were replicated five times. Statistical analysis was with MSTATC software, and included an analysis of covariance for growth measurements (initial size being the covariate).

On 29 May 1990, the trial started with the trees receiving 9 weeks of cool temperatures being transferred to a controlled temperature glasshouse (24°C day; 9°C nights and relative humidity 65 to 80% day; 30 to 60% nights). At the same time, automatic irrigation of the treatments receiving 9 weeks of drought stress was discontinued. Three weeks later, the same was done for treatments receiving 6 weeks of cold and/or 6 weeks of drought, and a further 3 weeks later the process was repeated for treatments requiring 3 weeks of cold and/or drought. Another three weeks later, irrigation was turned on, and trees transferred to the warm glasshouse (mean maximum 35°C; mean minimum 19°C) which was not as accurately controlled as the cool glasshouse. This meant that all stress treatments ended on the same day. During the 1991 season, the same was done, with stress treatments starting on 17 April 1991, but it was decided to lengthen the periods of stress from 0, 3, 6 and 9 weeks to 0, 4, 8 and 12 weeks, since no flowering had occurred the previous season.

Table 4.1. Treatments used in a 4 x 4 factorial design, with duration of low temperature as one factor, and duration of water deficit as the other.

Treatment Number	Factor A: Duration of Low Temperature (mean 23.6°C day / 8.9°C night). First season in parenthesis.	Factor B: Duration of withholding irrigation. First season in parenthesis.
1	0 weeks	0 weeks
2	0 weeks	(3) to 4 weeks
3	0 weeks	(6) to 8 weeks
4	0 weeks	(9) to 12 weeks
5	(3) to 4 weeks	0 weeks
6	(3) to 4 weeks	(3) to 4 weeks
7	(3) to 4 weeks	(6) to 8 weeks
8	(3) to 4 weeks	(9) to 12 weeks
9	(6) to 8 weeks	0 weeks
10	(6) to 8 weeks	(3) to 4 weeks
11	(6) to 8 weeks	(6) to 8 weeks
12	(6) to 8 weeks	(9) to 12 weeks
13	(9) to 12 weeks	0 weeks
14	(9) to 12 weeks	(3) to 4 weeks
15	(9) to 12 weeks	(6) to 8 weeks
16	(9) to 12 weeks	(9) to 12 weeks

4.2.2 *Data Collection*

4.2.2.1 Tree Growth

Tree height and stem diameters were measured regularly (approximately every two months) from the start of the trial. Tree height was measured with the use of a tape measure to the nearest cm from the potting soil surface to the top apical bud. Stem diameter was measured using a Mitutoyo[®] Digimatic digital vernier calliper, at a marked spot on the stem about 10 cm above the soil surface, in two directions (north-south and east-west).

4.2.2.2 Soil Moisture

Sixteen tensiometers, one for each treatment, were installed 20 cm deep in the potting soil about halfway between the tree and the side of the pots, and the soil matric potential was monitored for each treatment. A primitive lysimeter was set up using four plants; two in the cold glasshouse, and two in the warm glasshouse and the mass of water evapo-transpired at the -50 kPa soil water potential, was added to the pots when they reached -50 kPa, in order for the trees to survive.

4.2.2.3 Tree Stress Parameters

An attempt was made to measure leaf water potential using a pressure chamber, but the cashew has high latex content, which made it impossible to use this method. The latex oozed out of the petiole almost immediately after removing a leaf, and this made it impossible to see any water exuding from the petiole due to applied pressure. When it was discovered that leaf water potential could not be measured, other methods of quantifying tree stress had to be found. An ADC LCA3 portable photosynthesis meter was tried, but due to a combination of a faulty machine, and inexperienced personnel, the data gathered by this machine during the first year were non-valid and meaningless. During the second year relative water contents of the leaves were monitored, and a LI1600 Steady State Porometer was used to measure transpiration and diffusive resistance (to water vapour) of the stomata.

4.2.2.3.1 Relative Water Content (RWC)

Relative water content of cashew trees under different stress conditions was determined. Trees not used in the experiment were used for RWC measurements, since it is a destructive method. Eight trees were given the drought stress treatments of the rest of the trial (0, 4, 8 and 12 weeks of withholding irrigation), two trees per drought treatment. Ten discs, approximately 1 cm in diameter, were punched from one leaf of each of the two plants per treatment, weighed to get fresh mass (W_f), and were floated in a petri dish of distilled water, in an artificially illuminated growth chamber with a radiant flux density of about $300 \mu\text{mol m}^{-2} \text{s}^{-1}$ (estimated light compensation point), for 4 h to become turgid. After this they were removed from the water, carefully patted dry with paper towel, and the turgid mass (W_t) was determined. After this the discs were dried in a forced draught oven at 70°C to constant mass (24 to

36 hours) and the dry mass (W_d) was obtained. This procedure was repeated regularly, starting at 10:00 to 11:00 during the drought stress period. In all cases a Mettler^R electronic balance accurate to 10^{-3} g was used. The relative water content was then calculated:

$$\text{RWC (\%)} = \frac{(W_f - W_d)}{(W_t - W_d)} \times 100$$

4.2.2.3.2 Porometry

During the second year of the study, leaf transpiration and stomatal diffusive resistance were measured using a steady state or null balance porometer (LI 1600, Licor Inc., Lincoln, Nebraska, USA) to try and quantify tree stress. The most extreme treatments were measured (Control, drought only, cold only, and drought and cold combined) over the duration of the stress treatments. All other treatments fell within these four extremes. The youngest, fully expanded, mature leaf was measured in all cases because these were expected to be the most physiologically efficient leaves. Measurements were only made on clear, sunny days.

Transpiration (E) data were converted from the older units ($\text{mg cm}^{-2} \text{s}^{-1}$) to the more widely used units of $\text{mmol m}^{-2} \text{s}^{-1}$. Diffusive resistance was expressed as stomatal conductance (g_s) (= 1/diffusive resistance) since it is more meaningful and less prone to misinterpretations (Beadle *et al.*, 1987), and these data were converted from the units cm s^{-1} to more up to date SI units of $\mu\text{mol m}^{-2} \text{s}^{-1}$.

4.2.2.4 Destructive Harvest

At the beginning of the trial, three trees were destructively harvested and the starch contents of the different organs determined. After the first season's treatments had been applied, branch samples 0.8 to 1.5 cm thick were taken for starch analysis. The samples were dried in a forced draught oven at 70°C to constant mass, milled, and analysed for starch content as described in section 3.2.2.

At the end of the trial all trees were destructively harvested, and fresh and dry mass of leaves, stem and branches, and roots were determined. Total leaf area of each tree was determined using a Licor Leaf Area Meter (LI 3100). The different organs were dried to constant mass, milled and analysed as per section 3.2.2.

4.2.2.5 Leaf Anatomical Comparison

In order to determine the anatomical differences between leaves in the field and glasshouse, leaves of approximately the same age were sampled, embedded in wax, and cross-sections were made for microscope study. The full technique appears in Chapter 3 of this thesis.

4.3 RESULTS AND DISCUSSION

4.3.1 Environmental Conditions

4.3.1.1 Lysimeter

Primitive lysimeters were set up to determine the amount of water to add to the pots when the soil water potential reached -50 kPa as measured by tensiometer. In the warm glasshouse, soil water potential reached -50 kPa after 13 days of withdrawing irrigation, and at that point 230 g H₂O day⁻¹ was evapotranspiring (Fig. 4.1). Therefore 200 ml H₂O day⁻¹ (slightly less than actual ET) was applied as supplementary irrigation for tree survival, two weeks after withdrawing water. In the same way it was determined that in the cool glasshouse (24/9°C) (Fig. 4.1), ET occurred at a much lower rate, and after 31 days a soil water potential of -50 kPa was reached. By this stage the ET rate was 120 g H₂O day⁻¹. Therefore, drought stressed trees in the cool glasshouse were given 110 ml H₂O day⁻¹ after 31 days. This means that drought treated trees which only spent three to four weeks in the cool glasshouse, were given no supplementary irrigation. The volume of water (4.86 ± 0.48 l per 20 l pot) at soil field capacity was determined by calculating the difference between the mass of oven dried soil, and 3 h after soil was resaturated and free water allowed to drain out of the pots.

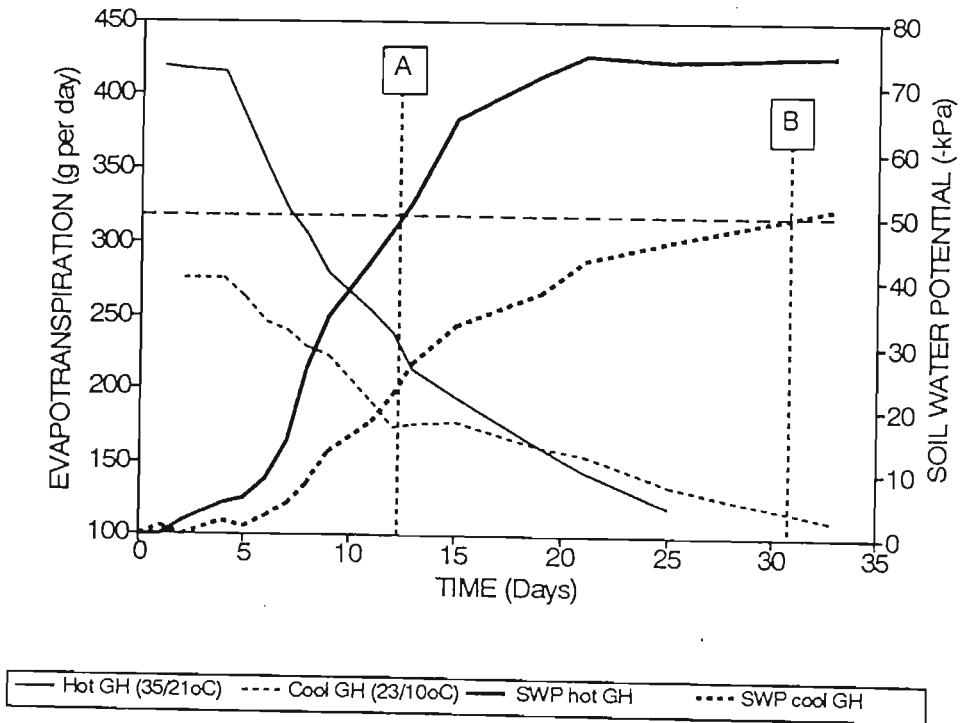


Fig. 4.1. Evapotranspiration and soil water potential of potted cashew trees as influenced by two temperature regimes, a cool glasshouse (24°C day/ 9°C nights) and a warm glasshouse (33/20°C). The time taken for trees in a warm (A) and cool (B) regime to reach - 50 kPa, and the ET rate at that point, were determined.

4.3.1.2 Treatment Temperature and Soil Water Tension Regimes

The maximum, minimum and mean daily temperatures were recorded in each glasshouse. This allowed the setting up of temperature profiles for each treatment (Fig's 4.2; 4.3). Each treatment had a calibrated tensiometer and from the soil water potential data collected, soil water profiles (Fig's 4.5; 4.6) were set up for the drought treated trees. Soil water potential (ψ_{soil}) is the sum of soil matric potential (τ) and osmotic potential (π_{soil}). Matric potential is predominantly influenced by capillary forces between the liquid - air interfaces of the fine pores (Beadle *et al.*, 1987), and it is therefore this component of soil water potential which is measured by tensiometer. Osmotic potential is usually negligible in non-saline soils (Beadle *et al.*, 1987). Hence the use of soil matric potential on the Y-axis of the soil tension profiles, as well as in the text in some cases.

The control trees had a τ varying between 0 and -4 kPa (Fig. 4.5A; 4.6A), permanently at field capacity. Three (Fig. 4.5B) to four weeks (Fig. 4.6B) of drought in a warm glasshouse was sufficient time for τ to decline to -70 kPa, albeit for a few days, but in a cool glasshouse τ was only able to decrease to c. -20 to -40 kPa. The longer durations of drought, in both warm and cool glasshouses, were able to force τ down to -60 to -70 kPa.

4.3.2 *Tree Growth*

4.3.2.1 Reproductive

The initial aim of studying stress effects on flowering was not able to be carried out since no flowering occurred. This could have been attributed to the juvenility of the cashew trees, which were c. 3 years old (from seed) at the end of the second year of the trial. However, Ohler (1979) reported that cashew trees have a very short juvenile period (as short as 6 months in ideal environments) and young trees (1 to 2 years) were observed by the author in Maputaland, and therefore this may not be a valid speculation.

Photosynthetically active radiation (PAR), as measured by the LI 1600 porometer's quantum sensor, ranged from 10 to 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ for dawn readings and 850 to 1250 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Outside PAR at midday over the period of measurement was 1750 to 1900 $\mu\text{mol m}^{-2} \text{s}^{-1}$. The light levels at midday inside the glasshouse were therefore 48 to 65 % of the PAR outside. Many authors (Agnoloni & Giuliani, 1977; Nair *et al.*, 1979; Ohler, 1979; van Eijnatten & Abubaker, 1983) have written about the sensitivity of cashew reproductive growth to sunlight. Field observations in Maputaland also showed that flowering was erratic on the shady side of the tree, but it was not determined whether this was due to low PAR or lower temperatures (possibly a combination of the two). The relatively low PAR in the glasshouses may have been the reason for the absence of flowering on trees in this trial.

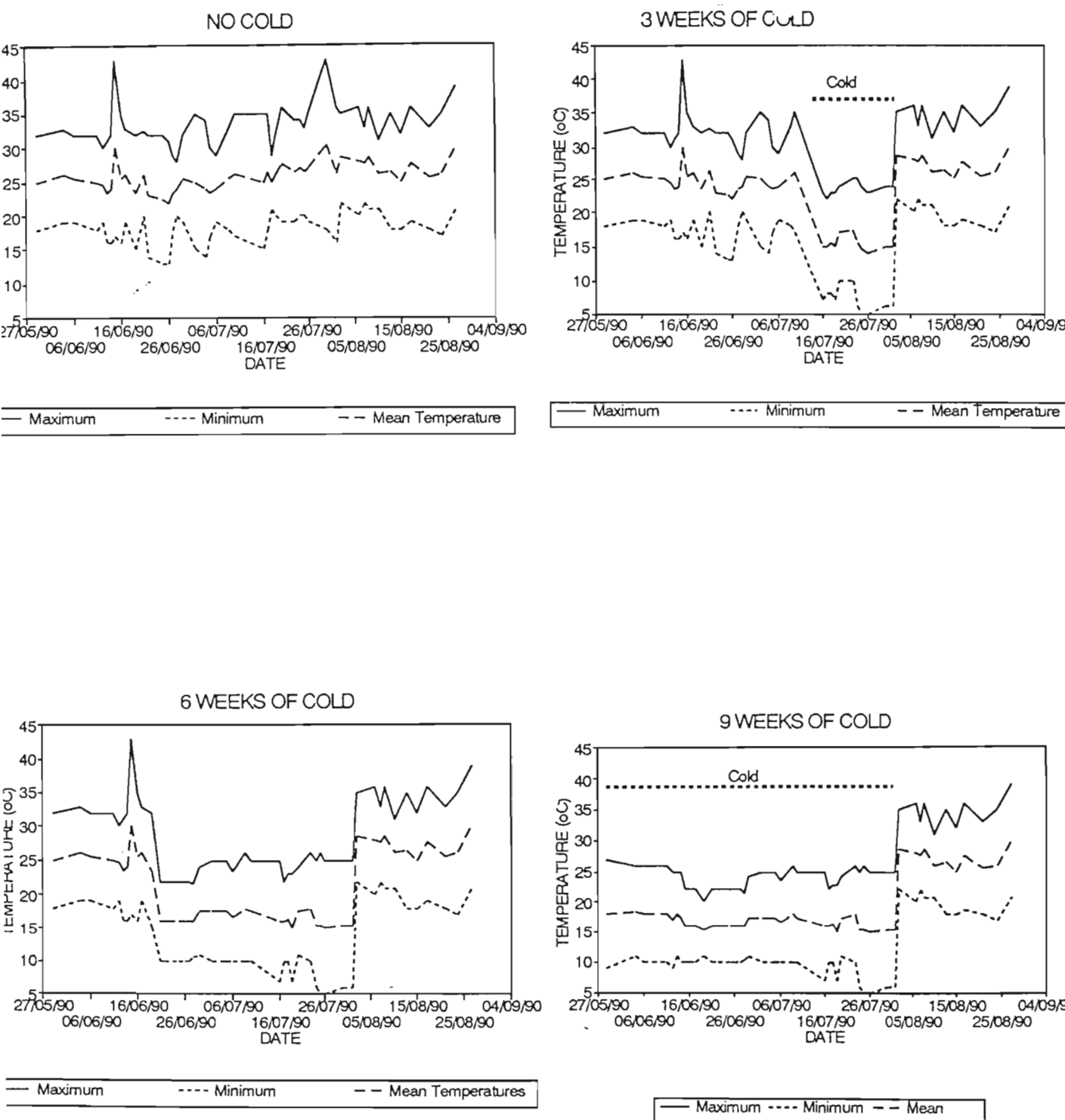


Fig.4.2. Temperature profiles for cashew trees experiencing 0, 3, 6 and 9 weeks of low temperatures during the 1990 season.

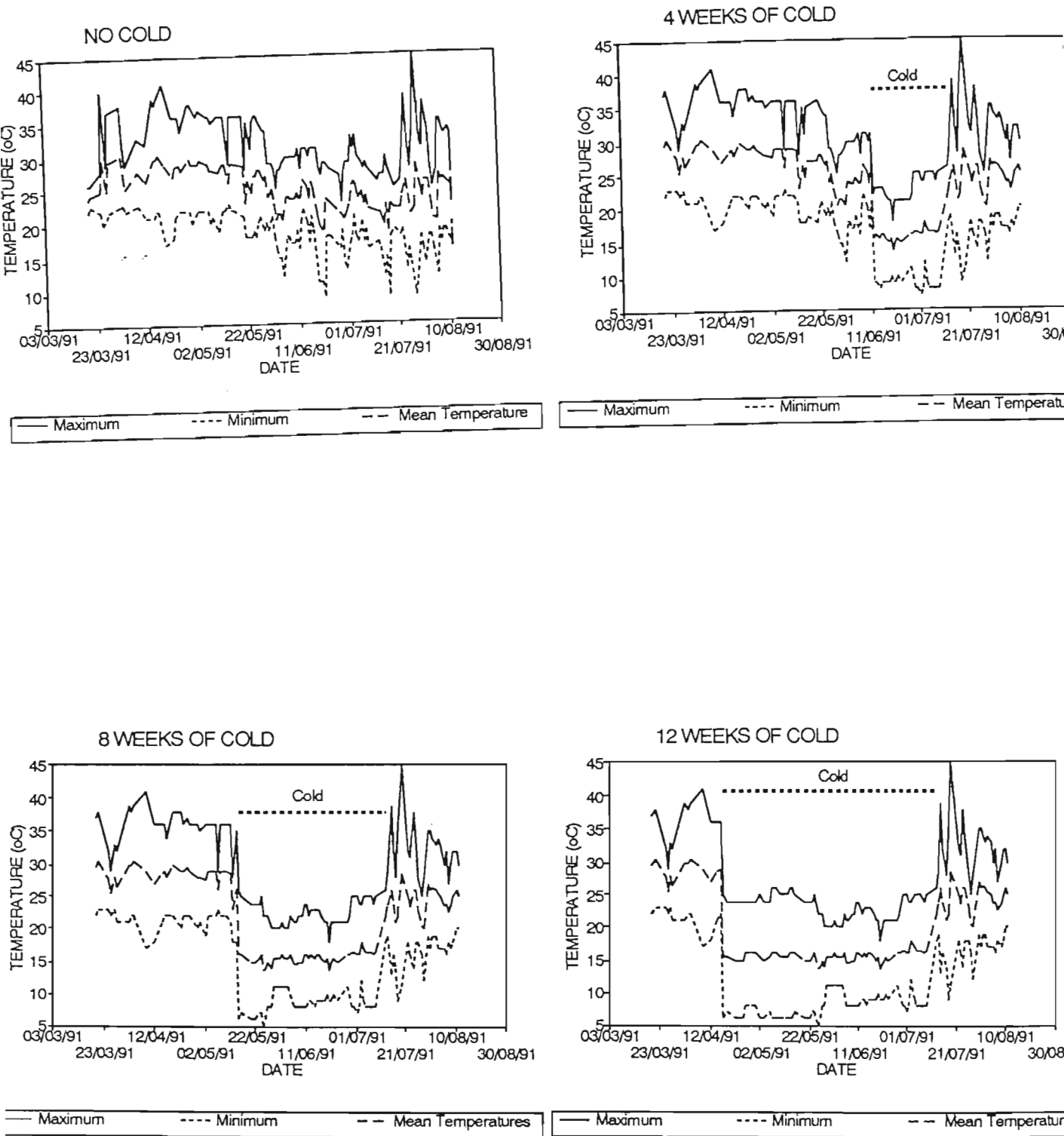


Fig.4.3. Temperature profiles for cashew trees experiencing 0, 4, 8 and 12 weeks of low temperatures during the 1991 season.

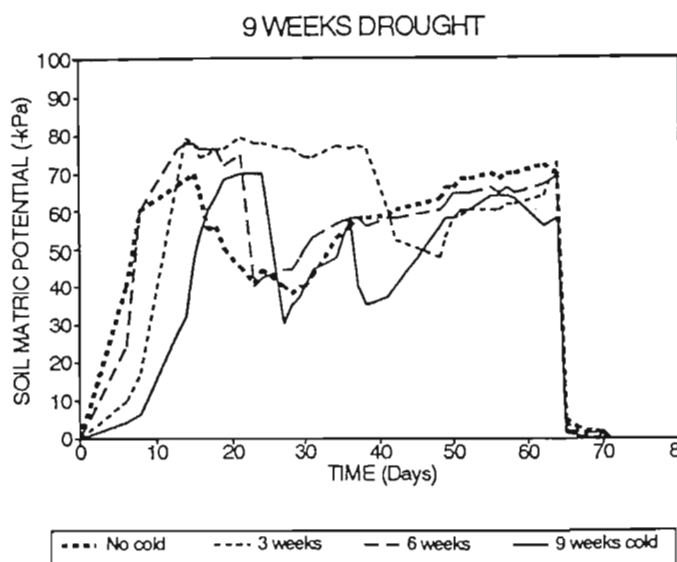
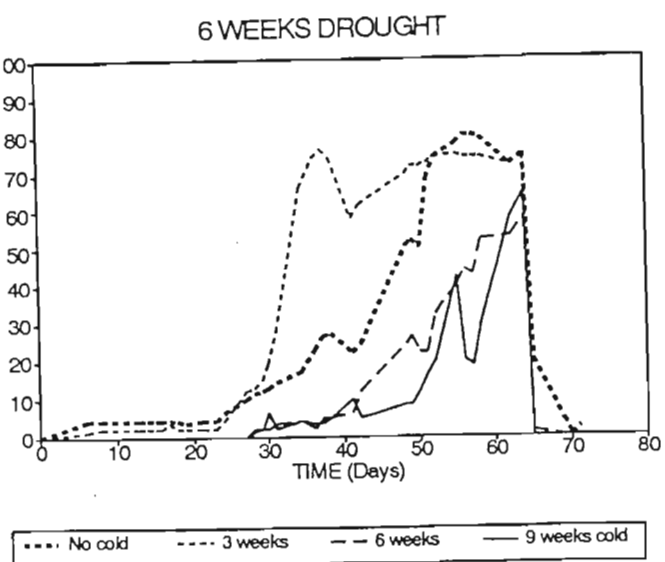
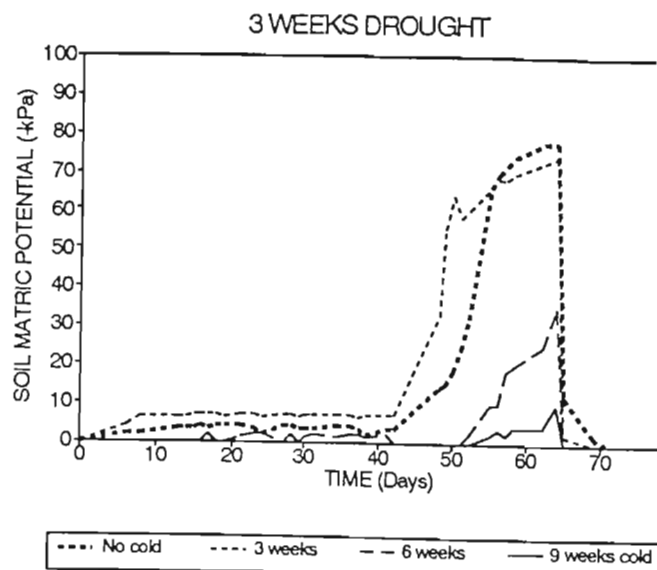
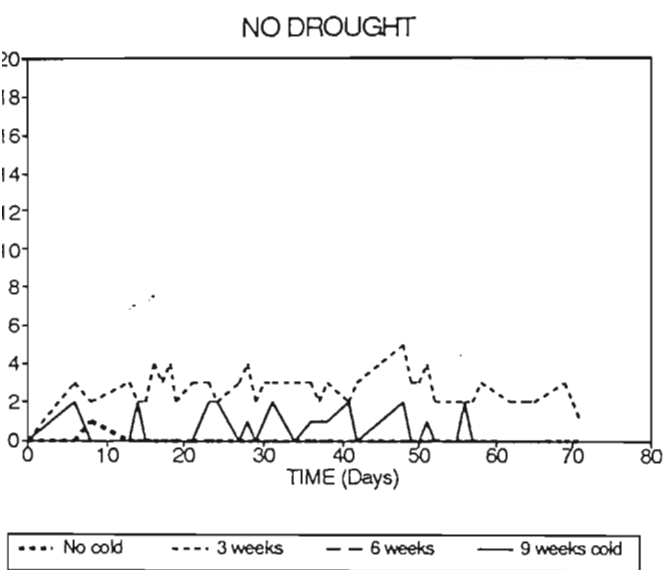


Fig.4.4. Soil water potential profiles for cashew trees experiencing 0, 3, 6 and 9 weeks of drought during the 1990 season.

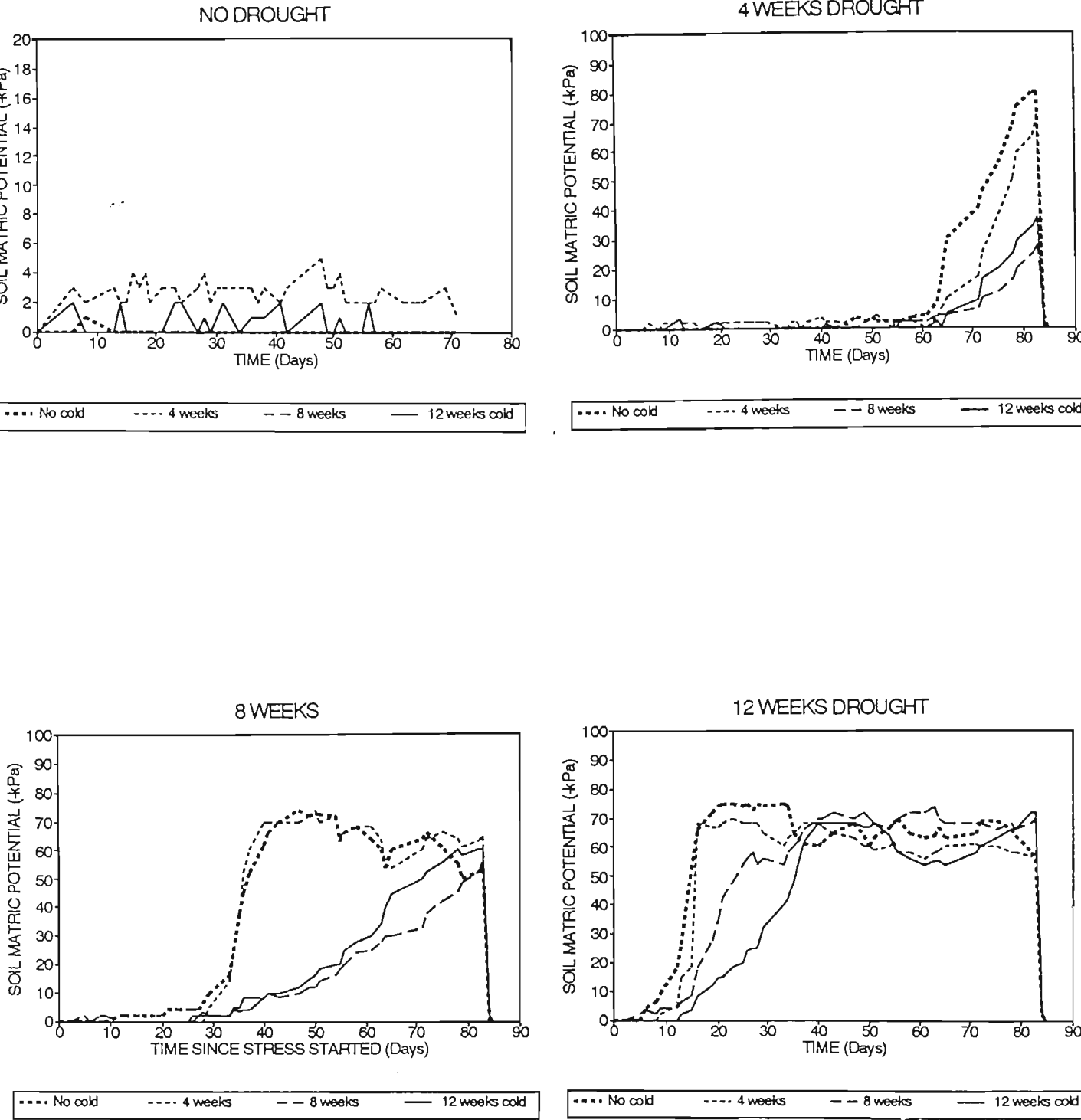


Fig.4.5. Soil water potential profiles for cashew trees experiencing 0, 4, 8 and 12 weeks of drought during the 1991 season.

Table 4.2. Tree height growth of cashew trees under different combinations of drought and low temperature stress.

TREATMENT FACTORS		GROWTH (cm) IN HEIGHT ^z FROM 18-6-90 TO:							
COLD (weeks)	DROUGHT (weeks)	6/8/90	21/9/90	26/10/90	5/12/90	22/4/91	2/7/91	16/9/91	11/11/91
MAIN EFFECTS: COLD									
0		5.83a	17.43a	36.11	52.96	104.06	104.59	109.2	112.59
4		5.21a	18.02a	37.79	56.78	103.76	104.68	109.5	115.2
8		1.66b	10.13b	31.87	53.42	105.62	106.51	115.66	119.07
12		0.78b	9.46b	27.89	45.81	88.84	89.83	94.24	98.69
LSD ($P \leq 0.01$)		3.066	6.248	10.7(ns)	16.9(ns)	29.0(ns)	28.6(ns)	26.9(ns)	26.4(ns)
MAIN EFFECTS: DROUGHT									
	0	4.55	14.09	33.63	52.54	105.2	105.88	113.75	116.75
	4	4.79	14.3	35.82	56.59	102.85	104.56	109.79	116.98
	8	2.88	14.78	34.88	54.33	102.4	102.95	108.87	112.33
	12	1.25	11.88	29.32	45.51	91.84	92.24	96.2	99.48
LSD ($P \leq 0.01$)		3.06(ns)	6.25(ns)	10.7(ns)	16.9(ns)	29.0(ns)	28.6(ns)	26.9(ns)	26.4(ns)
INTERACTIONS									
0	0	10.29	19.62	34.86	47.72	99.33	99.72	105.66	108.29
0	4	8.00	19.60	40.99	59.98	123.78	124.38	126.18	127.58
0	8	3.70	17.11	36.18	56.32	99.47	99.62	104.64	110.99
0	12	1.32	13.4	32.42	47.82	93.64	94.66	100.31	103.5
4	0	4.39	17.73	36.65	55.46	95.83	95.76	99.13	103.51
4	4	7.65	17.07	38.03	59.68	99.13	102.05	107.18	119.11
4	8	5.66	19.26	38.2	54.64	111.85	112.73	119.19	121.89
4	12	3.13	18.01	38.28	57.34	108.22	108.19	112.51	116.27
8	0	2.09	8.28	33.09	58.15	131.66	131.61	149.76	151.28
8	4	2.48	10.46	39.19	65.98	105.84	108.79	125.76	126.83
8	8	1.65	13.57	33.92	52.79	107.6	108.06	113.27	118.79
8	12	0.41	8.22	21.29	36.75	77.40	77.60	73.86	79.37
12	0	1.43	10.72	29.92	48.85	93.97	96.43	100.45	103.92
12	4	1.03	10.07	25.08	40.7	82.63	83.03	80.03	94.41
12	8	0.52	9.19	31.24	53.54	90.65	91.38	98.35	97.63
12	12	0.15	7.88	25.31	40.13	88.09	88.50	98.13	98.8
Interaction LSD ($P \leq 0.01$)		6.13(ns)	12.5(ns)	21.4(ns)	33.8(ns)	58.0(ns)	57.2(ns)	53.8(ns)	52.8(ns)
CV (%)		108.38	54.05	38.18	38.53	34.38	33.60	29.93	28.20

^z Means followed by the same symbol in each column are not significantly different. Where the analysis of variance showed no significant main effects or interactions, only the means and LSD are presented, and no symbols inserted.

Table 4.3. Stem diameter growth of cashew trees under different combinations of drought and low temperature stress.

TREATMENT FACTORS		GROWTH (mm) IN STEM DIAMETER FROM 18-6-90 TO:							
COLD (weeks)	DROUGHT (weeks)	6/8/90	21/9/90	26/10/90	5/12/90	22/4/91	2/7/91	16/9/91	11/11/91
MAIN EFFECTS COLD									
0		1.73a	3.48a	5.11a	6.68a	11.33	12.57a	13.49a	15.47a
4		1.13b	2.16b	3.97b	5.74ab	10.46	11.61ab	11.87ab	13.44ab
8		0.3c	1.16c	2.9c	4.61b	9.29	9.64c	10.1c	11.59b
12		0.32c	1.45bc	3.17bc	4.83b	9.74	9.71bc	10.48bc	12.49b
LSD ($P \leq 0.01$)		0.414	0.785	1.04	1.57	1.67(ns)	1.92	1.76	2.24
MAIN EFFECTS: DROUGHT									
	0	1.46a	2.74a	4.5a	6.26	11.27	12.11	12.65	14.9
	4	1.09a	2.25ab	4.06ab	5.8	9.77	10.82	11.6	13.31
	8	0.42b	1.61b	3.26b	4.86	10.04	10.41	11.16	12.48
	12	0.53b	1.65b	3.33b	4.95	9.74	10.2	10.53	12.31
LSD ($P \leq 0.01$)		0.414	0.785	1.04	1.57(ns)	1.67(ns)	1.9(ns)	1.76(ns)	2.23(ns)
INTERACTIONS									
0	0	3.31a	5.47	6.49	7.53	12.8	14.11	15.43	18.7
0	4	1.84b	3.23	4.96	6.45	10.99	12.74	13.5	15.31
0	8	0.82c	2.61	4.43	6.18	10.67	11.59	12.47	13.83
0	12	0.97cd	2.6	4.57	6.56	10.83	11.85	12.57	14.06
4	0	1.87b	2.42	5.06	7.71	12.33	13.74	14.03	15.86
4	4	1.65bc	2.58	4.08	5.58	10.29	11.86	12.11	12.85
4	8	0.44d	1.59	3.2	4.8	10.25	11.17	11.61	13.11
4	12	0.57d	2.04	3.52	4.9	8.98	9.67	9.74	11.94
8	0	0.38d	1.32	3.02	4.72	10.3	11.12	11.28	13.83
8	4	0.34d	1.22	3.33	5.41	8.79	8.91	10.02	11.74
8	8	0.16d	0.99	2.58	4.19	9.42	9.69	10	10.29
8	12	0.33d	1.09	2.68	4.11	8.66	8.86	9.1	10.49
12	0	0.29d	1.73	3.45	5.1	9.64	9.47	9.85	11.2
12	4	0.52d	1.98	3.85	5.74	9.02	9.75	10.78	13.32
12	8	0.24d	1.23	2.82	4.25	9.82	9.18	10.56	12.69
12	12	0.24d	0.86	2.57	4.22	10.49	10.42	10.72	12.75
Interaction LSD ($P \leq 0.01$)		0.828	1.57(ns)	2.08(ns)	3.13(ns)	3.33(ns)	3.8(ns)	3.5(ns)	4.5(ns)
CV (%)		56.43	45.37	32.69	34.14	19.54	21.04	18.20	20.11

^z Means followed by the same symbol in each column are not significantly different. Where the analysis of variance showed no significant differences, only the means and LSD are presented, and no symbols inserted.

4.3.2.2 Vegetative

There were no significant differences between treatments as far as initial height and stem diameter were concerned. Analysis of covariance, with initial tree height (for tree height growth), and initial stem diameter (for stem diameter growth measurements) as covariates, was nonsignificant for both these parameters of tree growth. The main effects of drought stress on tree height growth (Table 4.2) were non significant throughout the trial. Cold, on the other hand, had a highly significant ($P \leq 0.01$) depressing effect on tree mean height extension during the first four months of this trial (9 weeks of treatments and the two months following stress). This was a stage of rapid growth, and low temperatures affected tree growth more than did drought stress. This demonstrated the sensitivity of cashew trees to low temperatures, while being relatively drought tolerant. During and after the following year's treatments there was no significant effect on tree height growth. The interaction effects of drought and cool temperatures on tree height growth were nonsignificant, and therefore only main effects are of consequence, but interaction data were included for interest.

Stem diameter, which is possibly a more reliable indicator of tree vigour, was affected highly significantly ($P \leq 0.01$) by the interaction of cold and drought c. 2 months after the treatments were applied for the first time (Table 4.3). However, this was the only time that significant interactions were evident.

The main effects of cool temperatures on stem diameter growth were highly significant ($P \leq 0.01$), from the time that treatments were applied until c. 6 months afterward (5 December 1990) (Table 4.3); the longer the duration of cold, the less growth. Stem diameter growth of trees receiving 9 weeks of cold had recovered somewhat by the time treatments were reapplied. The application of treatments on 17 April 1990 resulted in further significant ($P \leq 0.01$) depression of growth in all the cold treatments.

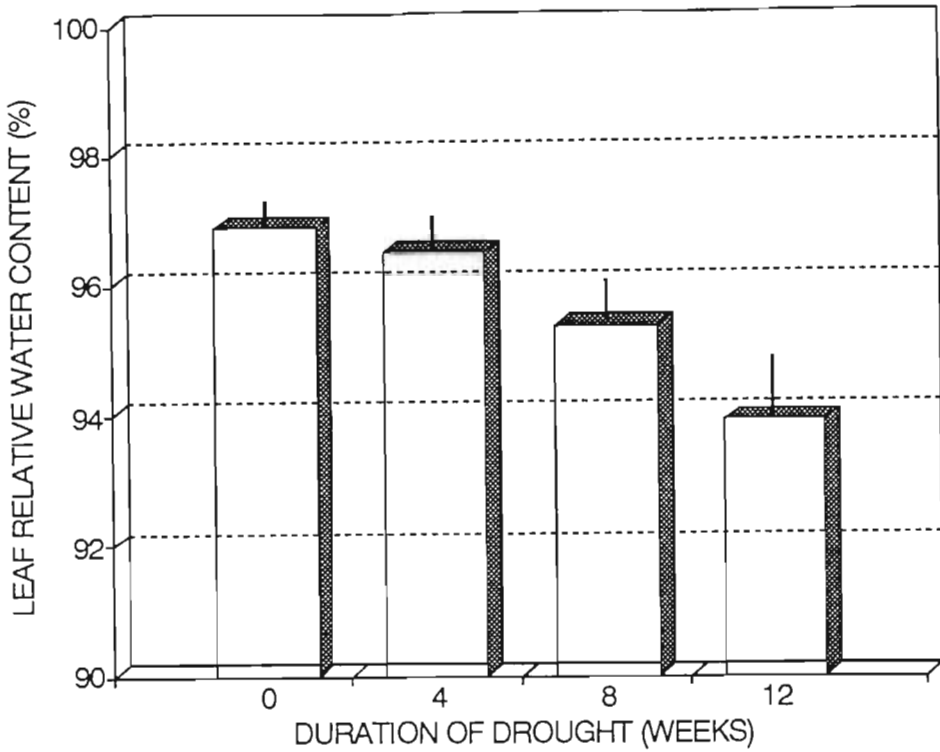
Drought by itself (main effects) (Table 4.3) also had highly significant effects ($P \leq 0.01$) on the mean stem diameter growth of cashew trees receiving 6 and 9 weeks of drought for a period of 5 months after the trial commenced. After this, the differences were nonsignificant, although the downward trend in stem diameter growth with increasing duration of drought remained.

4.3.3 *Tree Stress*

4.3.3.1 Relative Water Content

Relative water content (RWC) of leaf discs of the outermost leaves sampled at 10h00 to 11h00 varied from 96.2% to 97.5% in leaves of trees receiving cold only. Trees with 4 weeks of drought followed a similar pattern to control trees throughout the drought stress period (Fig. 4.6). With increasing drought duration RWC declined markedly, indicating that the plants were experiencing stress. This stress was also reflected by chlorosis, and ultimately abscission, of the leaves on the inside of the canopy, symptoms similar to N-deficiency. This was extremely puzzling as it appeared to indicate that cashew trees are able to partition water to the growing points against the osmotic and concentration gradients in the plant. This may be a means of drought resistance (possibly linked to latex physiology) and deserves further investigation. Upon rewatering, the relative water content recovered to levels similar to the controls within 7 days, but full physiological recovery took much longer.

(A)



(B)

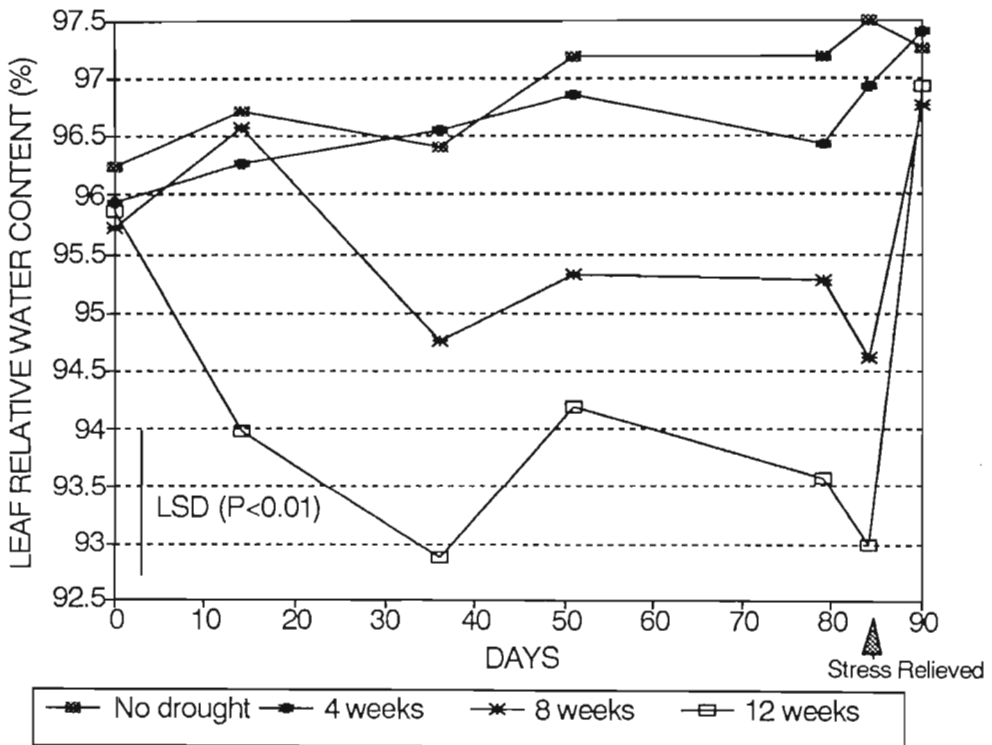


Fig. 4.6

Leaf relative water contents at 10h00 to 11h00 as affected by different durations of drought stress: Treatment means (bars indicate standard errors), (A) and distribution over 12 weeks (B).

4.3.3.2 Porometry

Drought stress symptoms became evident 2 to 3 weeks after soil water potential reached -50kPa. It therefore took much longer for trees experiencing drought and cold to show symptoms, if at all. The symptoms included

a yellowing of leaves from the inside of the canopy outwards, after which leaves wilted and dropped. Cold stress was displayed as a russetting effect on the leaf laminae.

Over the duration of the stress treatments, stomatal conductance (g_s), of leaves on control trees, occurred in the range from 216.8 to 390.2 $\text{mmol m}^{-2} \text{s}^{-1}$ (Fig. 4.8 A) with a mean of $304.1 \pm 46.81 \text{ mmol m}^{-2} \text{s}^{-1}$ (Fig 4.7A) at or shortly after dawn. Drought, and cold individually had depressing effects on mean dawn g_s , and cold and drought in combination resulted in even lower dawn g_s ($137.4 \pm 73.19 \text{ mmol m}^{-2}$). The deepening stress, particularly from combined drought -cold stress, made it more and more difficult for leaf turgor to recover, as seen in the relative water contents of drought stressed trees (Fig.4.6). Mean dawn g_s (Fig.4.9A) was slightly higher than midday g_s for control, and considerably higher for drought treatments, but not so for trees receiving cold, and a combination of cold and drought. This indicated that even though PAR was much higher at midday, the cold factor was keeping the stomata from opening fully.

In control trees, dawn transpiration (E) levels (Fig. 4.9B) varied from 0.463 to 1.129 $\text{mmol m}^{-2} \text{s}^{-1}$ (mean 0.791 ± 0.243). Dawn E decreased with drought (mean $0.509 \pm 0.164 \text{ mmol m}^{-2} \text{s}^{-1}$), cold ($0.507 \pm 0.108 \text{ mmol m}^{-2} \text{s}^{-1}$) and even further with a combination of the two ($0.361 \pm 0.131 \text{ mmol m}^{-2} \text{s}^{-1}$) (Fig. 4.7B). Midday E was higher than dawn E for all treatments, but stress decreased midday dawn over controls by 55.1% for drought stressed trees, 47.9% for cold stressed, and 68.3% for cold-drought stress. The control trees were able to transpire at relatively high rates at midday because of relatively high g_s , which in turn indicates a tree which was able to flourish in its environment. In the drought stressed trees the roots were not able to supply sufficient water to satisfy the atmospheric and other demands for water, and as a survival mechanism, the stomata shut down to conserve moisture. It has long been known that stressful conditions increase abscisic acid (ABA) levels in plant tissue. ABA exercises a powerful control over guard cell action, and low concentrations (10^{-6} M) cause stomata to close (Salisbury & Ross, 1978). This is a probable explanation for the decreased g_s and E from the stress factors applied in this trial, when compared to control trees.

Regression analysis between τ and dawn g_s of trees receiving drought (Fig 4.10A) showed this decreasing g_s with less available soil water. Regressions between these two parameters for cold, and cold-drought treatments were not significant. In order to determine the relationships between E and g_s , linear regression analysis was carried out. High regression coefficients (r^2) were obtained for dawn data of trees receiving cold ($r^2 = 0.671$) (Fig. 4.10B), and both dawn ($r^2 = 0.867$) and midday ($r^2 = 0.913$) data of the most extreme treatment, drought - cold combination (Fig. 4.11). This indicates that, for these treatments, E was highly dependent on g_s which appeared to be controlled by cool temperatures in the morning. By midday it had warmed sufficiently for stomatal control to become uncoupled from temperature, and hence a low regression at midday for the cold treated plants. For the drought-cold stressed trees, the combination of drought and cold appeared to regulate g_s , although cold may have been the more dominant factor. In the drought treatment, the little water available was, in all likelihood, being used by the plant metabolic mechanisms, less water actually transpiring, and therefore E was less dependent on g_s .

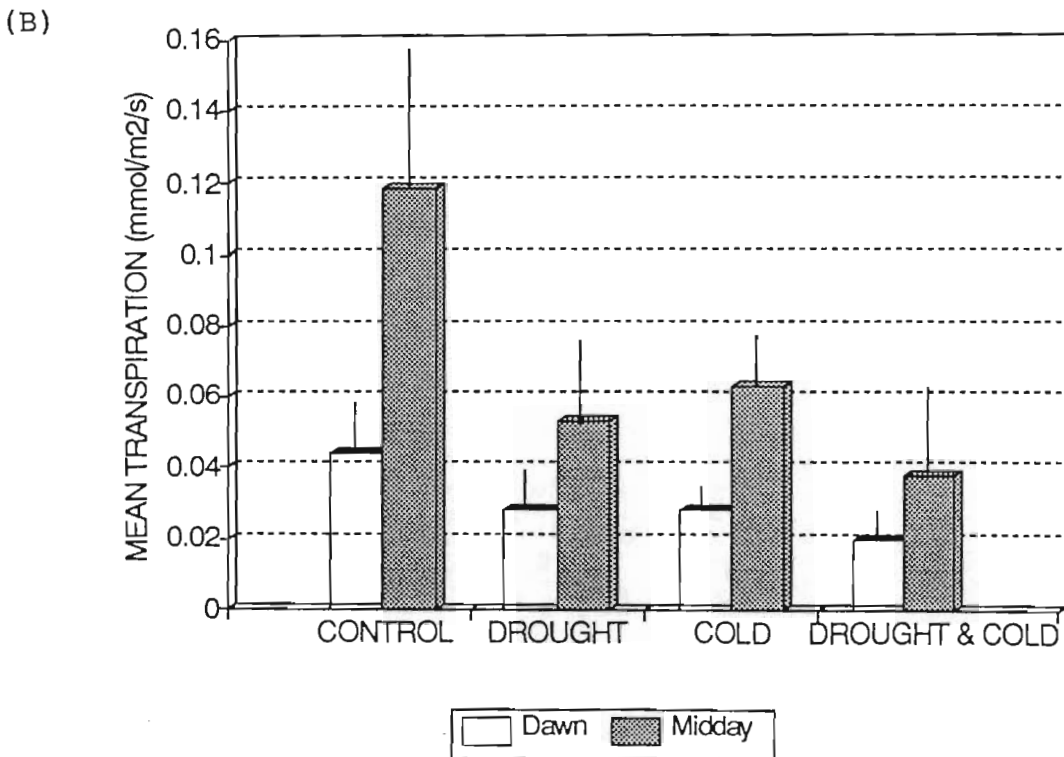
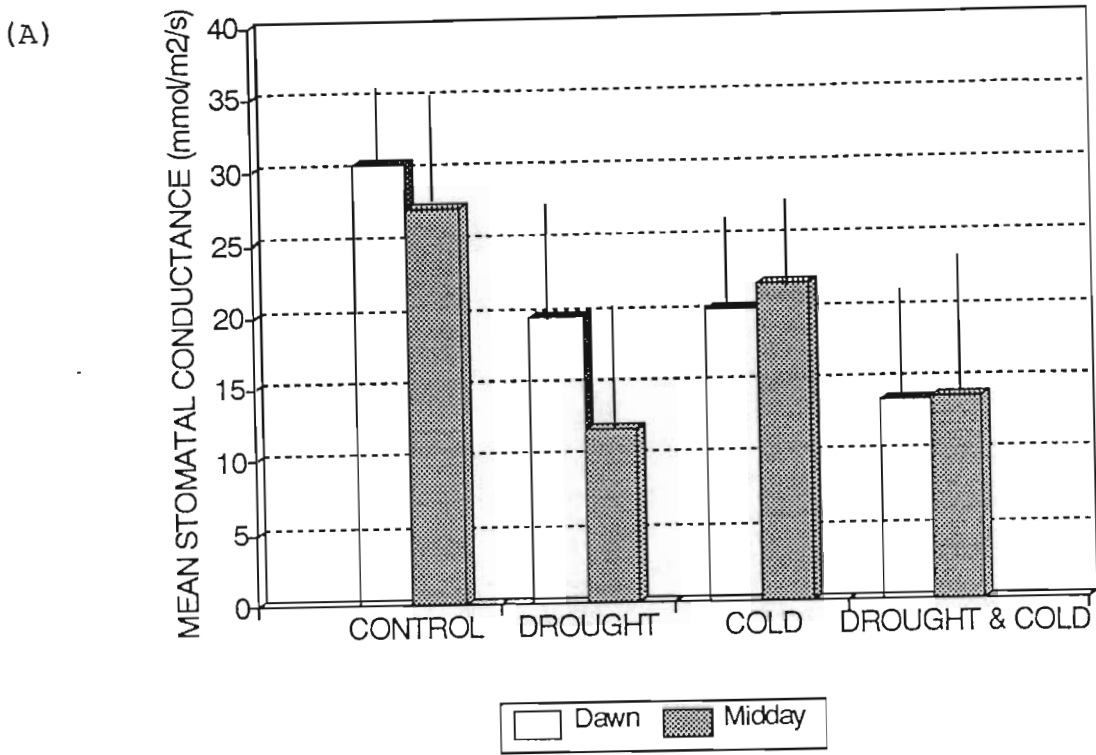


Fig. 4.7. Dawn and midday stomatal conductance (A) and transpiration (B) over 12 weeks as affected by cold and/or drought application.

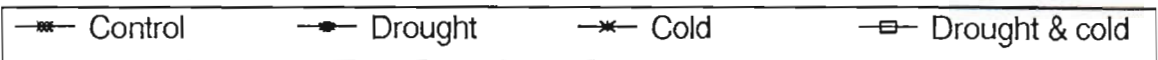
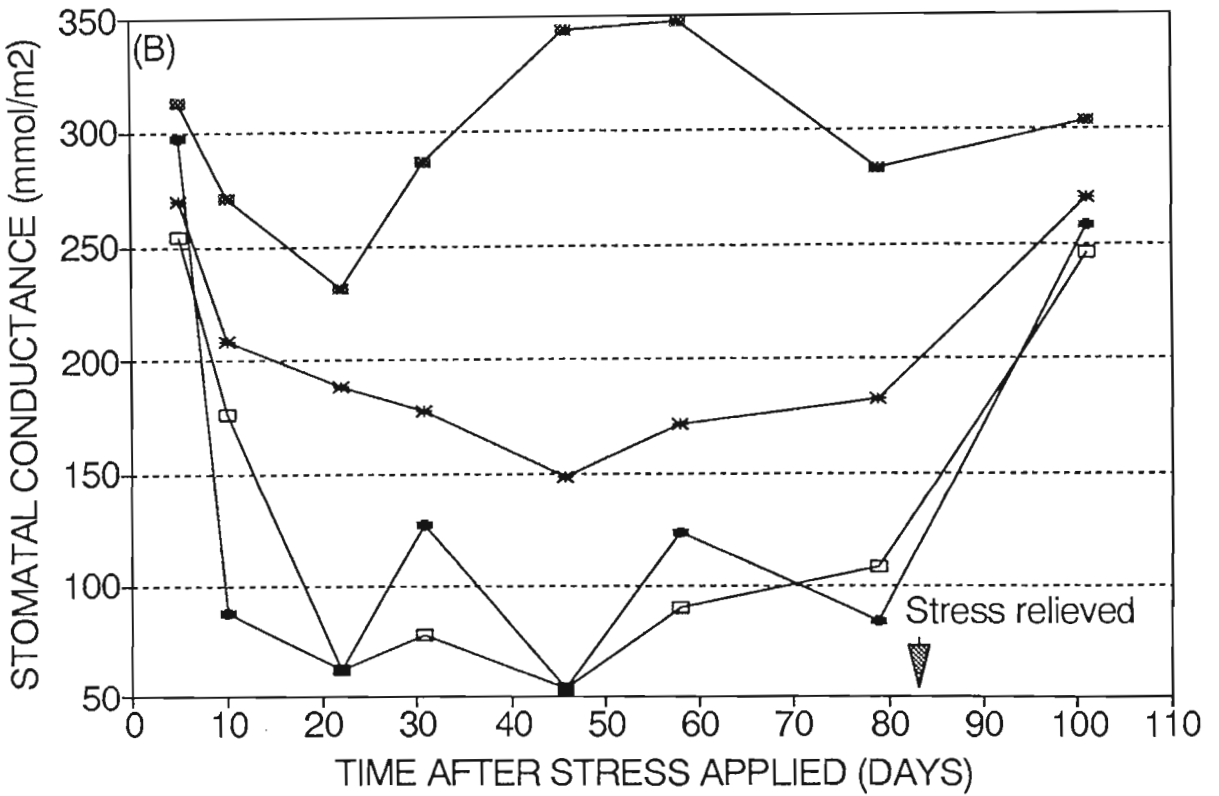
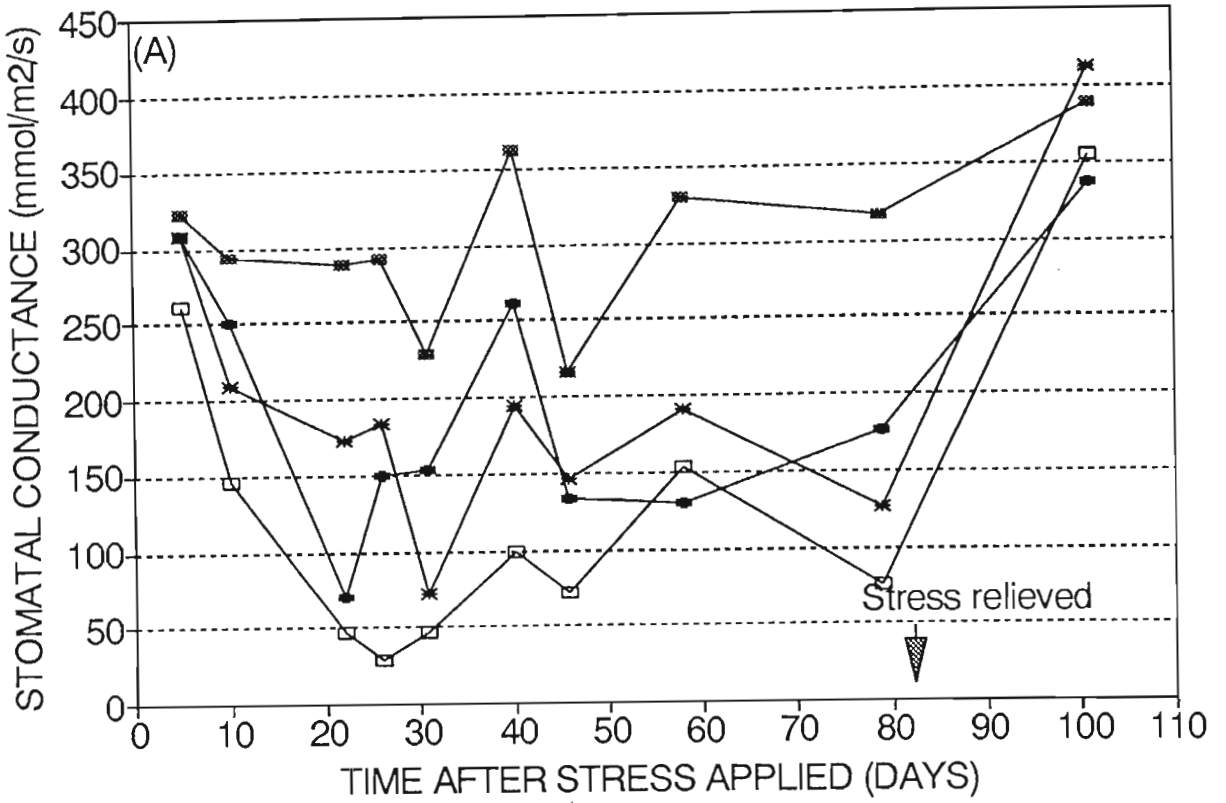


Fig. 4.8. Stomatal conductance at dawn (A), and midday (B) of trees receiving no stress, drought and/or cold stress for 12 weeks.

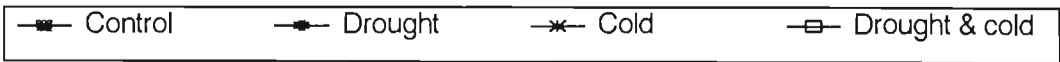
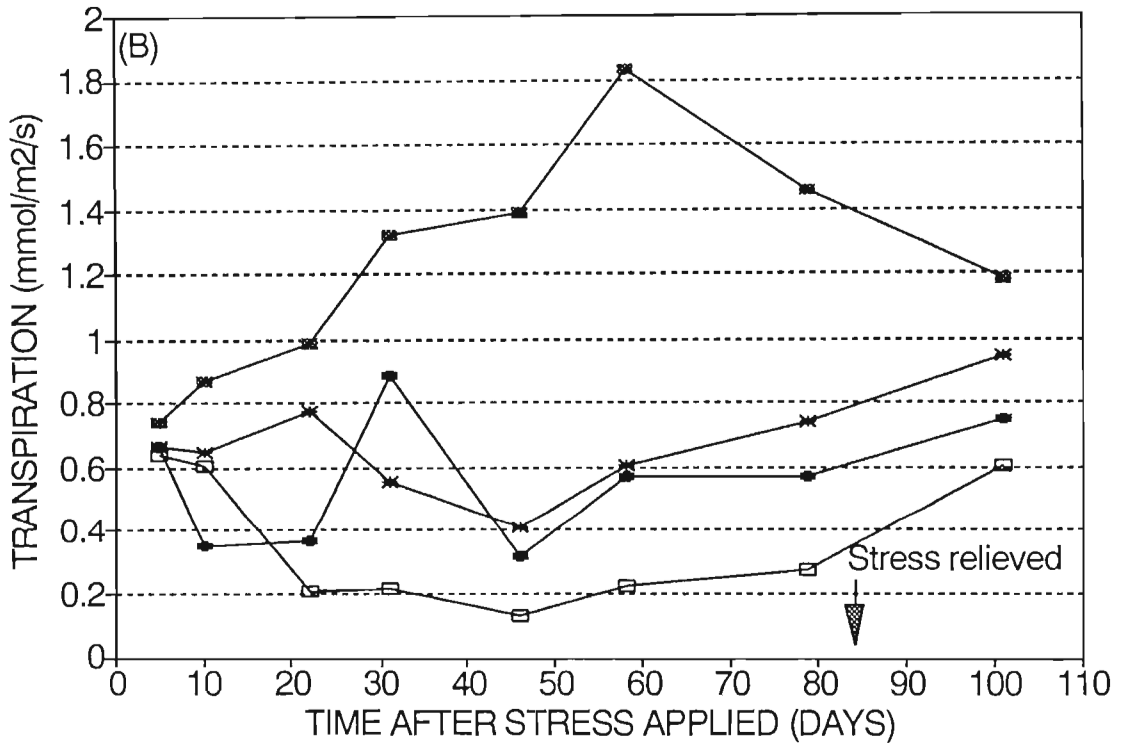
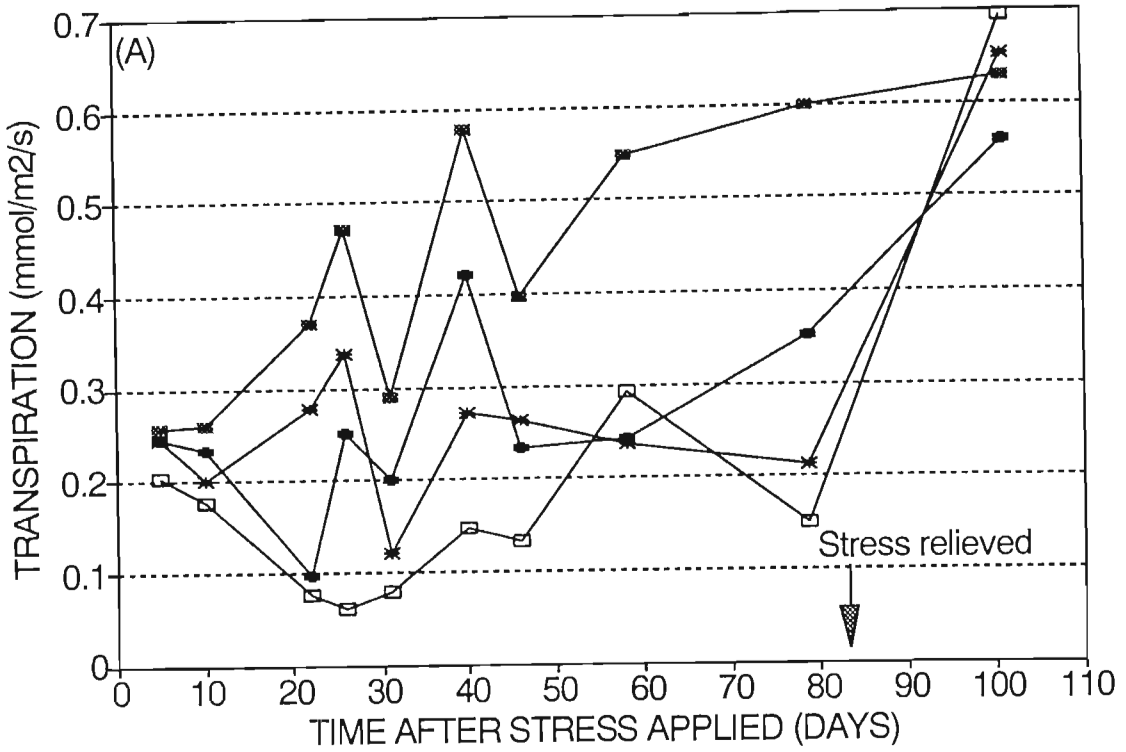


Fig. 4.9. Transpiration at dawn (A), and midday (B) of cashew leaves over a 12 week period as affected by drought and/or cold stress.

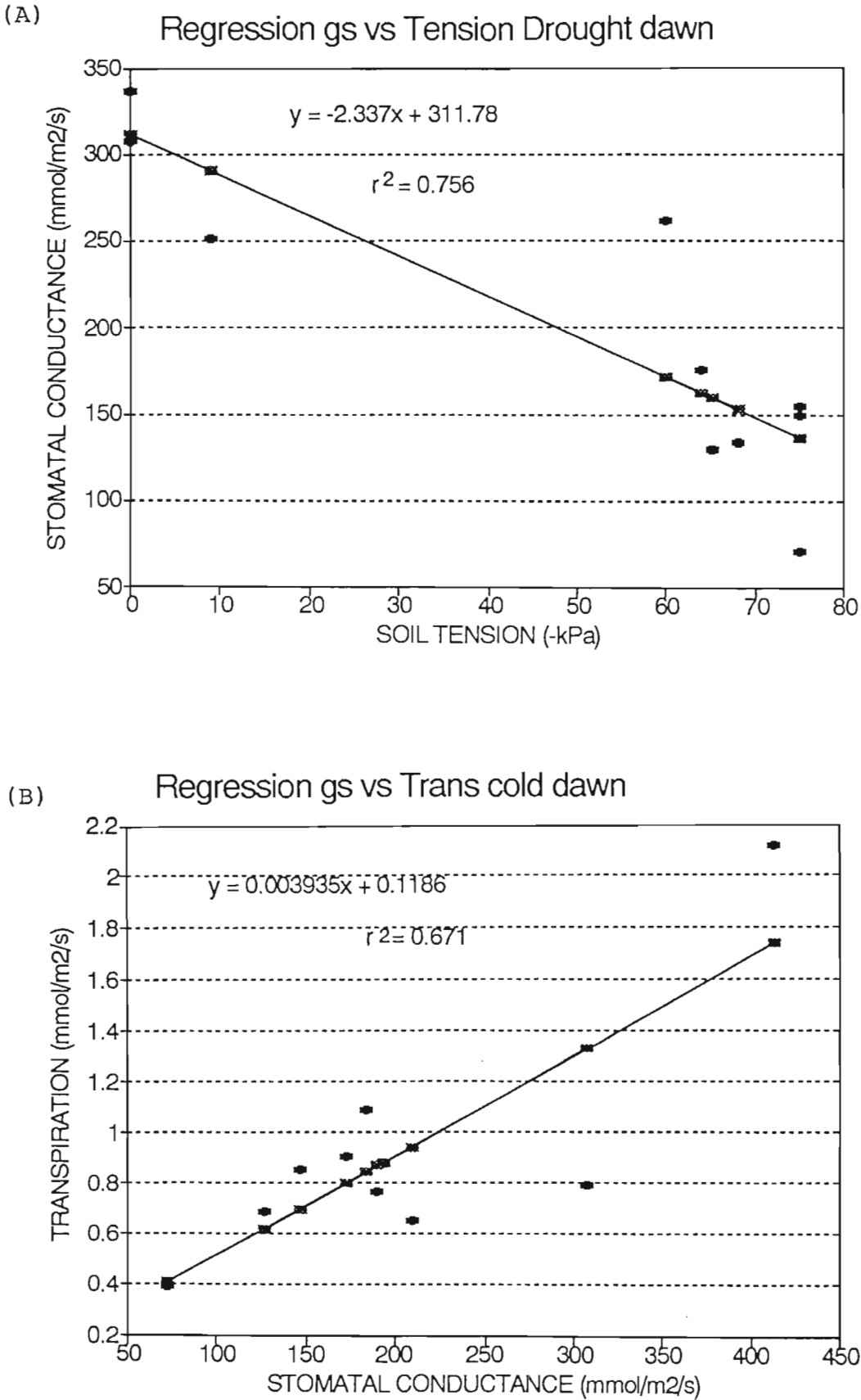


Fig. 4.10. Relationships between: A. soil matric potential (τ) and dawn stomatal conductance (g_s) of drought stressed trees; and B. transpiration (E) and g_s at dawn for cold stressed trees.

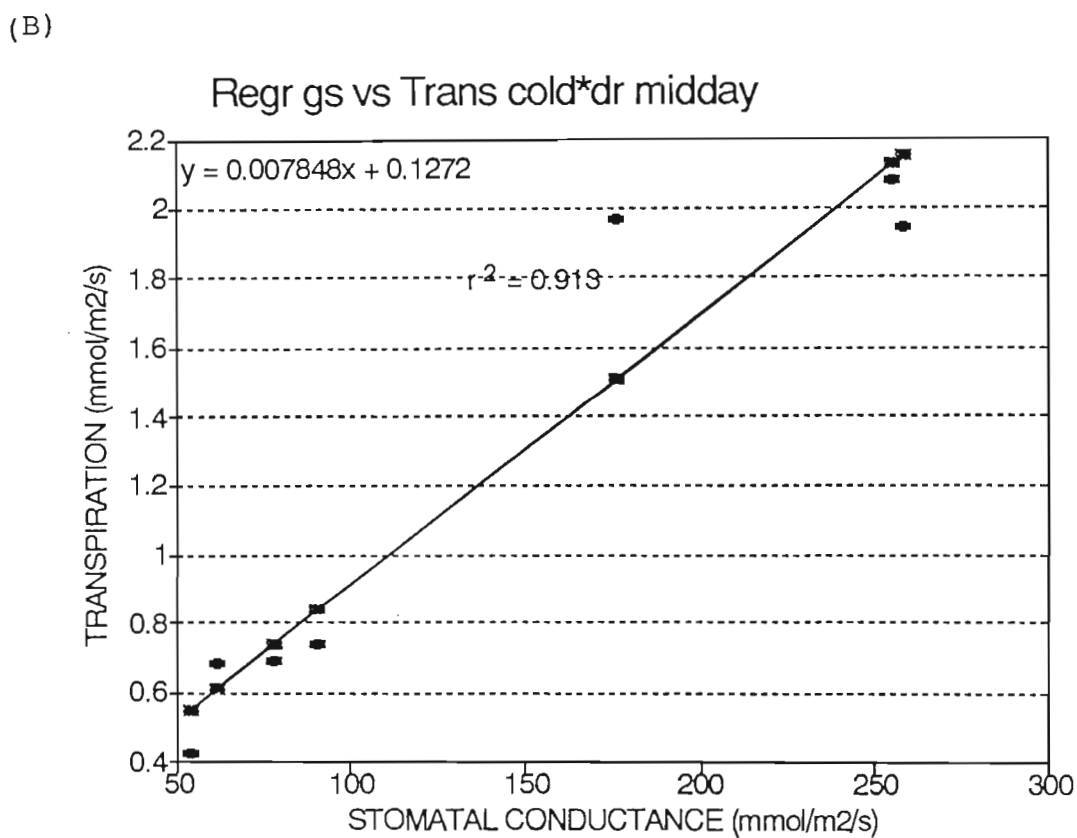
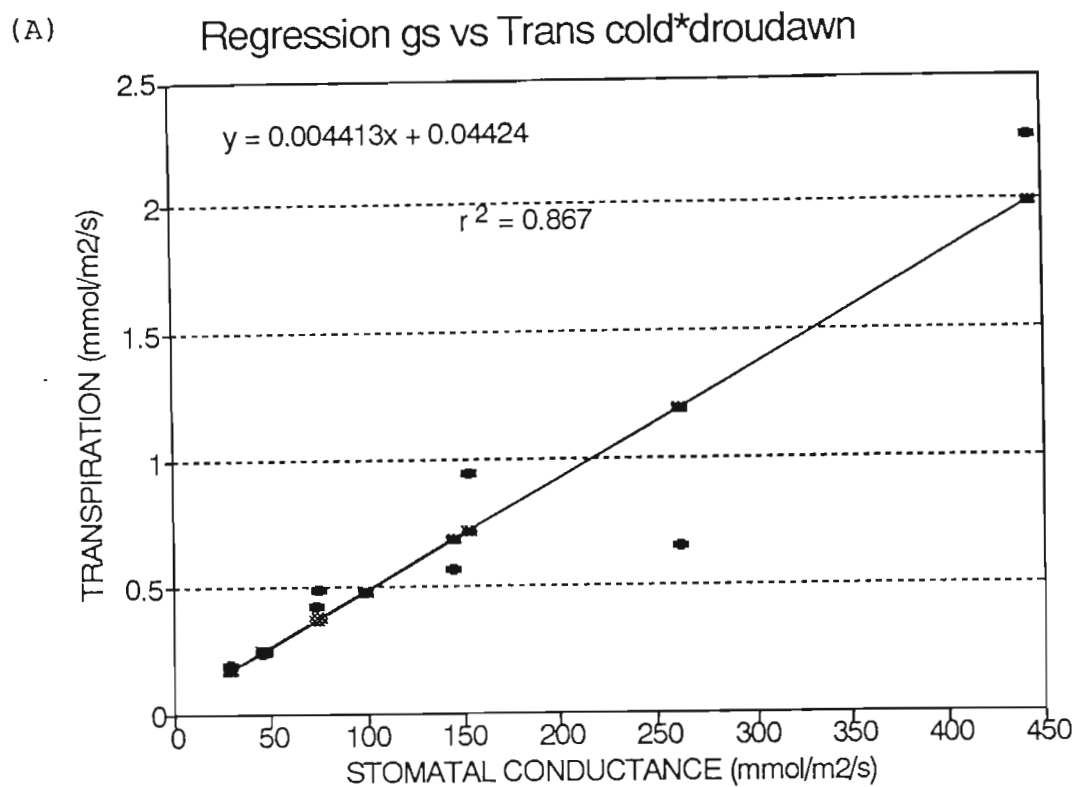
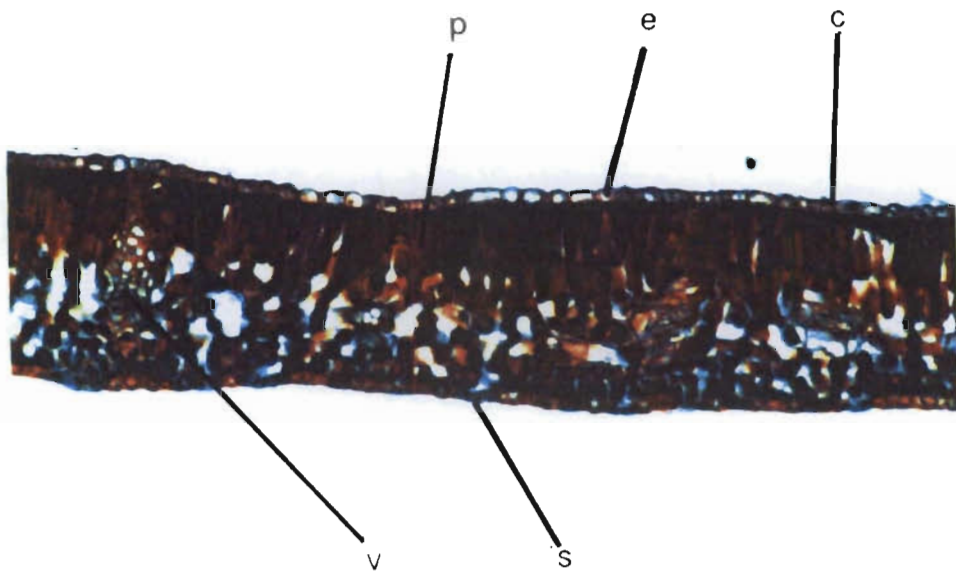


Fig. 4.11. Relationships between transpiration (E) and stomatal conductance (g_s) at dawn (A) and midday (B) of trees receiving a combination of drought and cold stress.

A)



B)

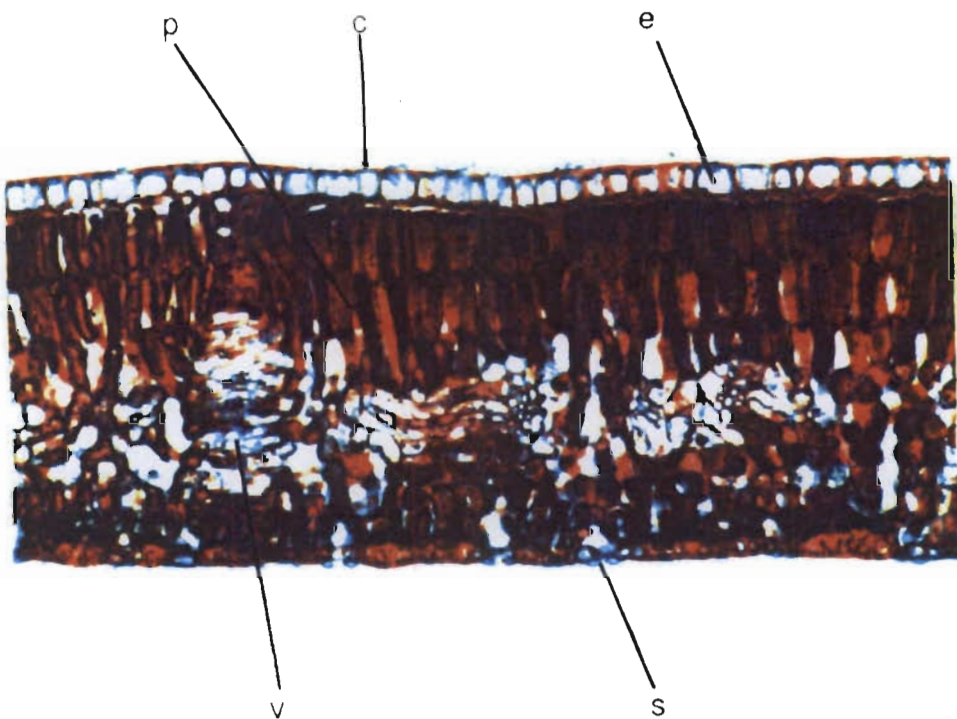


Plate 4.1

Cross-sections through cashew leaves of approximately the same age under glasshouse (A) and field (B) conditions. Note stomata (s) only on the adaxial surface, thinner cuticle (c), epidermal layers (e), palisade parenchyma (p), and overall leaf thickness of leaves from a glasshouse. Vascular bundles = v.

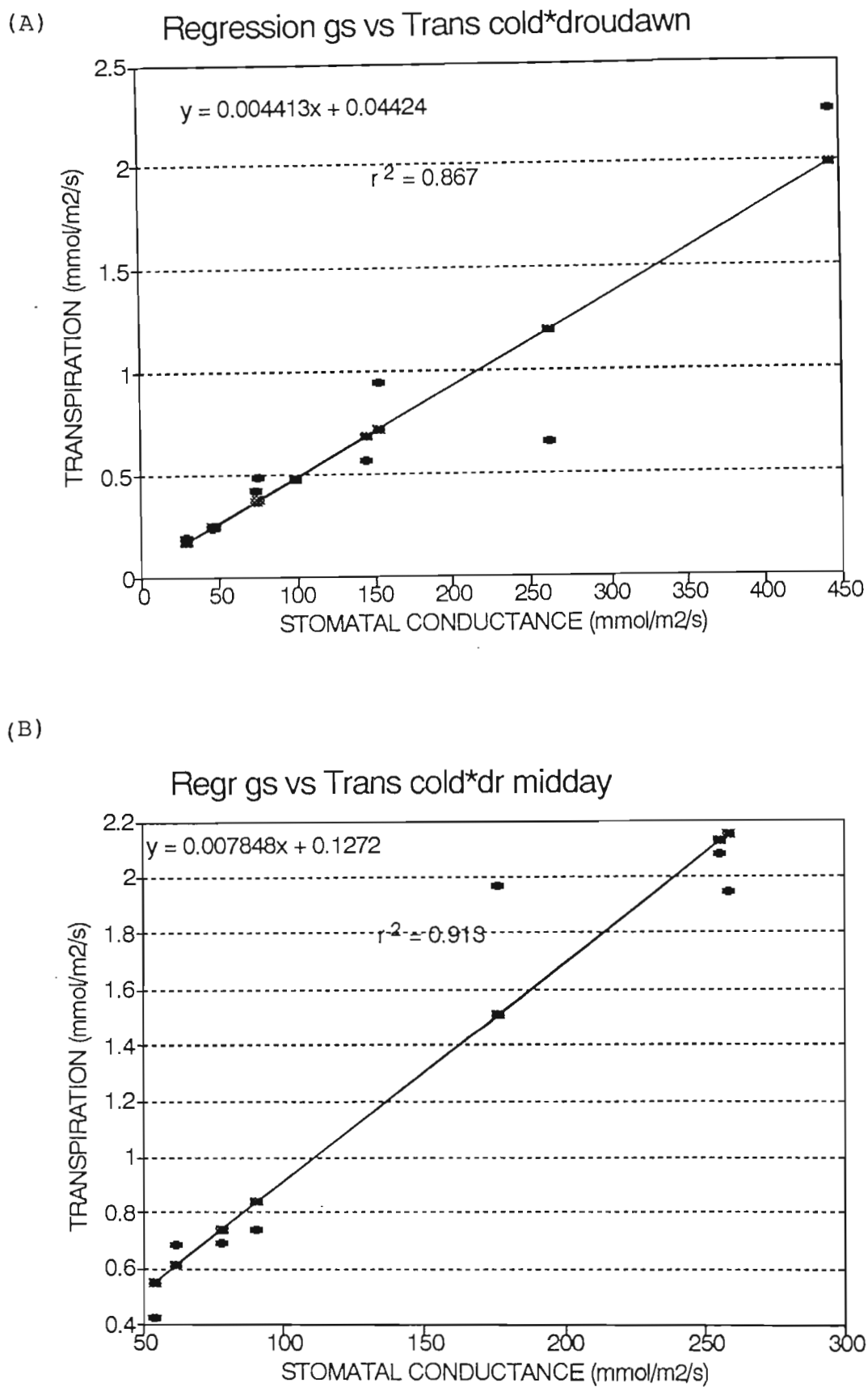


Fig. 4.11. Relationships between transpiration (E) and stomatal conductance (g_s) at dawn (A) and midday (B) of trees receiving a combination of drought and cold stress.

glasshouse. This is a possible explanation for the significantly dominant effects of cold on leaf dry matter production. The main effects of cold on stem and root dry matter production were once again significant ($P \leq 0.01$). This confirms the sensitivity of the tropically originated cashew tree, which is known to be tolerant to drought, and is therefore not affected by drought to the extent of cold stress. Furthermore, the latex system in cashew and mango leaves appears to be a mechanism to maintain leaf turgor (and drought tolerance) under conditions of drought, but not cold, stress.

Table 4.4. Leaf, stem and root dry mass, leaf area and number of leaves produced by cashew trees after 18 months under different combinations of drought and low temperature stress.

TREATMENT FACTORS		NUMBER OF LEAVES	DRY MASS (g)			LEAF AREA (cm ²)
COLD (weeks)	DROUGHT (weeks)		LEAF	STEM	ROOTS	
MAIN EFFECTS: COLD						
	0	138.5a	78.0a	337.4a	178.6a	6380a
	4	117.9ab	65.9ab	279.7ab	136.2b	4945ab
	8	93.87b	58.8b	211.4b	126.2a	4705b
	12	97.87b	64.2b	217.5b	110.7b	5104ab
LSD		28.14 **	12.83 **	90.70 **	36.62 **	1454.0 **
MAIN EFFECTS: DROUGHT						
	0	106.6	66.6	268.9	126.1	5300
	4	109.8	63.7	264.1	159.6	5838
	8	116.3	69.2	267.7	136.6	5214
	12	115.4	67.4	245.3	129.4	4781
LSD		(ns)	(ns)	(ns)	(ns)	(ns)
INTERACTIONS						
0	0	155.4a	91.5a	386.3	211.0	7182
0	4	135.4abc	76.9ab	377.3	170.1	6864
0	8	136.2abc	70.0abc	314.7	190.4	5408
0	12	127.0abcd	73.6abc	271.5	142.9	6068
4	0	91.6de	62.7bc	297.1	92.36	4939
4	4	150.4ab	74.3abc	248.8	176.8	6032
4	8	120.2abcd	73.9abc	336.0	130.1	6049
4	12	109.4bcd	52.8bc	236.7	145.4	2755
8	0	94.46cde	51.0c	206.5	112.8	5231
8	4	57.61e	49.2c	222.7	143.7	4647
8	8	108.4bcd	63.8bc	200.4	120.4	4386
8	12	115.0abcd	71.0abc	215.8	127.7	4557
12	0	85.0de	61.1bc	185.8	88.12	3846
12	4	95.7cde	54.5bc	207.4	147.7	5810
12	8	100.4cd	69.0abc	219.5	105.5	5017
12	12	110.4bcd	72.3abc	257.1	101.7	5744
Interaction LSD		42.31*	25.67**	(ns)	(ns)	(ns)
CV%		29.85	22.86	41.16	31.05	32.69

² Means followed by the same symbol in each sub-column are not significantly different. Where the analysis of variance showed no significant main effects or interactions, only the means are presented, and no symbols inserted. Main effect or interaction significance level is indicated by * ($P \leq 0.05$) and ** ($P \leq 0.01$).

4.3.5 Starch Levels

The mean starch levels were confounded by the loss of a major proportion of samples taken for analysis, when the oven they were in caught alight. Some means are only from two or three samples, the mean starch contents of the stem and leaves being affected. In these cases only the standard error of all data, and not LSD's have been included.

Starch levels at the beginning of the trial from a single tree, and before treatment application for the second season from three destructively harvested trees (Fig. 4.12) were determined. Tap root had the highest starch concentration followed by stems and leaves. Over approximately one year the starch levels in the tap root increased from 6.1 to 10.16 g 100 g⁻¹ DM (66.5% increase). This is typical of young plants, which grow quickly at first, using up most of their photosynthates in growth, but when the growth starts slowing, storage carbohydrates in the roots increase (Kozlowski, 1992). During the second year the plant organs were subdivided (Fig. 4.12B) for starch analysis. Once again the results were typical of woody plants, the major proportion of starch being found in the order: tap root > crown > fibrous roots ≈ rest of stem and branches > mature leaves > young leaves.

In mid April of the second year, branches 0.5 to 1.5 mm diameter were sampled from each tree to see whether there were any carry-over effects on starch content from the previous season's stress treatments (Fig. 4.13). There was no significant carry over effect in the branches due to main effects or interactions of cold and drought. However, there was a trend towards increasing starch levels with increasing stress, particularly cold stress. This is in agreement with field data from field trials which showed decreased starch levels in winter, and Whiley *et al.* (1989) who reported increased starch content of mango roots at low temperature regimes.

The starch content of roots, stems and leaves were determined again after destructive harvest. There was a significant main effect of the cold factor on root starch (Fig. 4.14A), but in this case root starch decreased with increasing cold. There was no significant effect on root starch content by drought (Fig. 4.14B), or the interaction of drought and cold (Fig 4.14C). A possible explanation for the decrease in root starch may be that cashew trees, being of tropical origin, had a lower photosynthesis rate at the low temperature regime (24/9°C) and mobilised starch after returning plants to the warm environment due to severe leaf abscission. By the time of destructive harvest, the plants that experienced cool conditions for the longest period, had barely flushed, leaves were still relatively young (1 to 2 months), and many of them possibly still net assimilate sinks. In trees which lost all or almost all their leaves there was a high likelihood of heat stress due to depleted cooling system, ie. transpiration cooling. In these plants net respiration may have been high, and since tropical trees have a particularly high carbohydrate depletion (c. 65% of assimilated C used in respiration) (Kira, 1975), the stored reserves would have been depleted rapidly.

Mean leaf starch content of control tree was 1.12 ± 0.257 g 100g⁻¹ DM at destructive harvest. There was a slight rise in leaf starch content with stress conditions, but this was not significant. Starch content of stems of control trees was 9.61 ± 2.047 g 100 g⁻¹ DM. There was a downward trend of starch content, particularly with longer cold stress. Inexplicably the starch levels of trees experiencing 12 weeks of drought and a short period

of low temperature stress increased by c. 28 % to 12.1 to 12.5 g 100 g⁻¹ DM. Many stem and leaf samples were lost in a fire, as previously mentioned, and therefore it will be difficult to come to any conclusion regarding stress effects on starch levels in these organs.

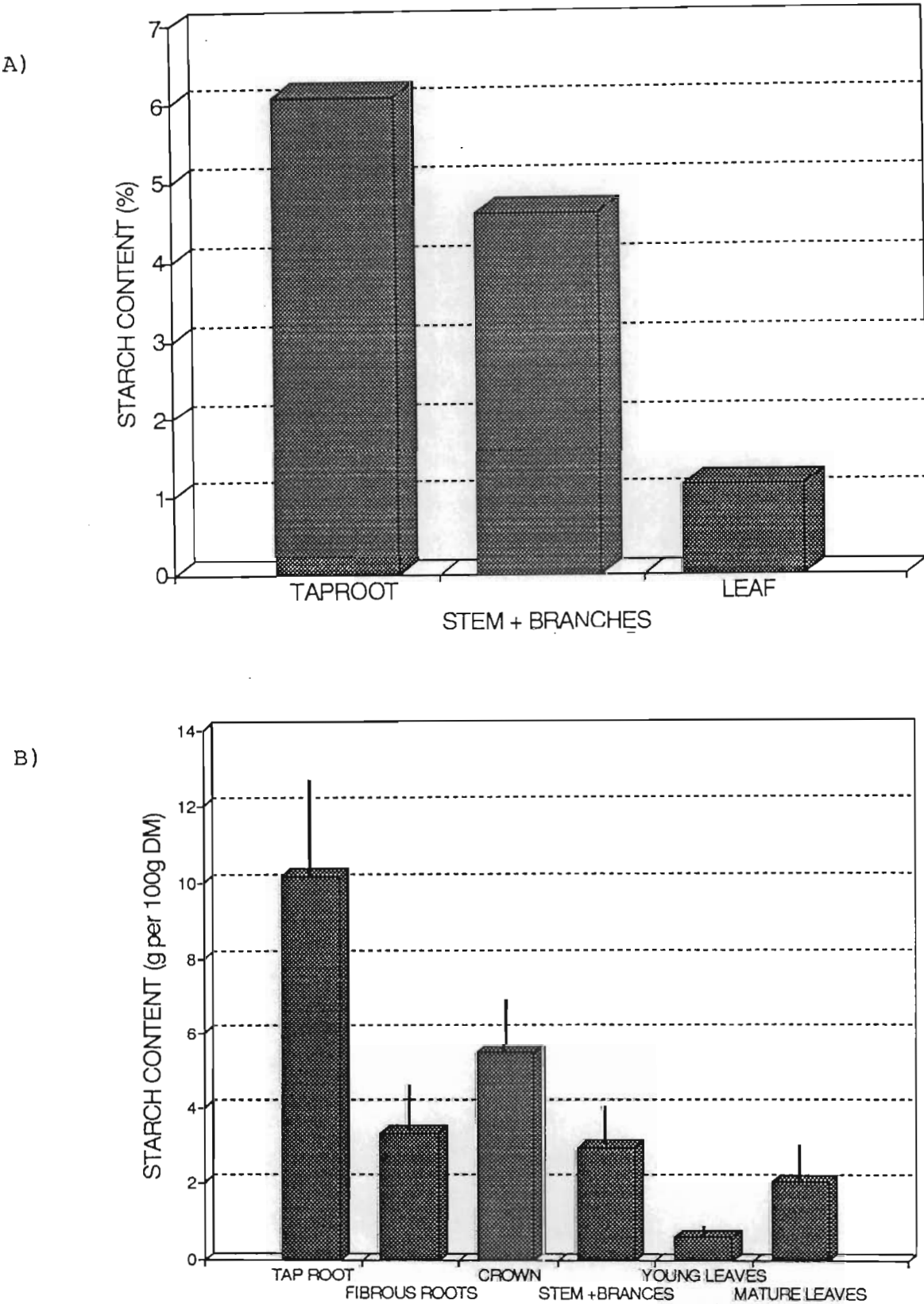


Fig. 4.12. Starch levels of different organs of young cashew trees used in glasshouse trials before cold and drought and/or cold treatment application in 1990 (A), and 1991 (B).

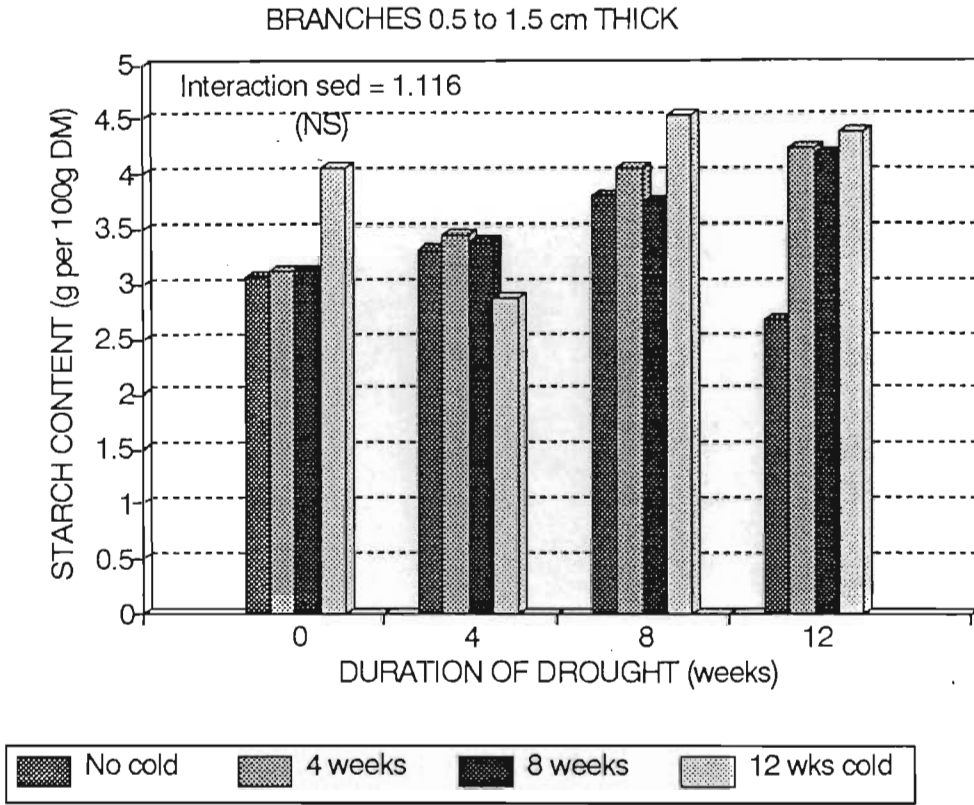
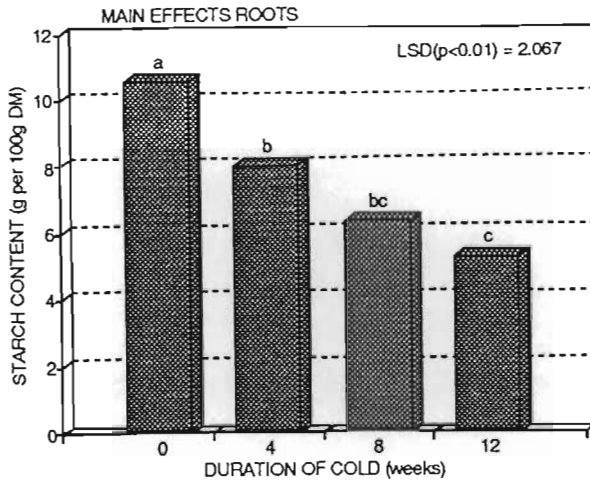
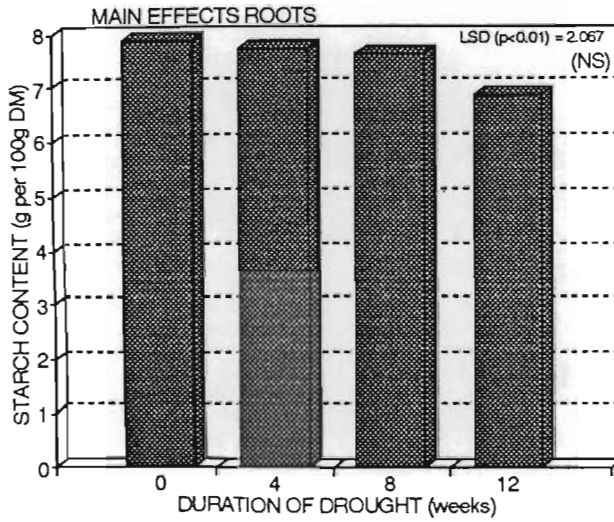


Fig. 4.13. Starch content of cashew shoots 0.5 to 1.5 mm diameter as affected by cold and/or drought treatment c. one year prior to sampling.

(A)



(B)



(C)

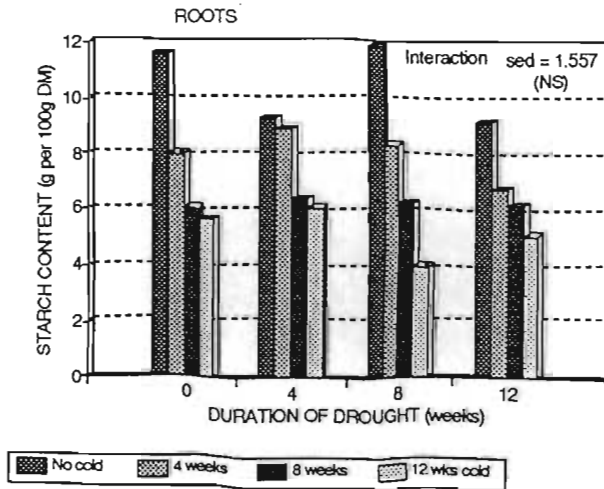
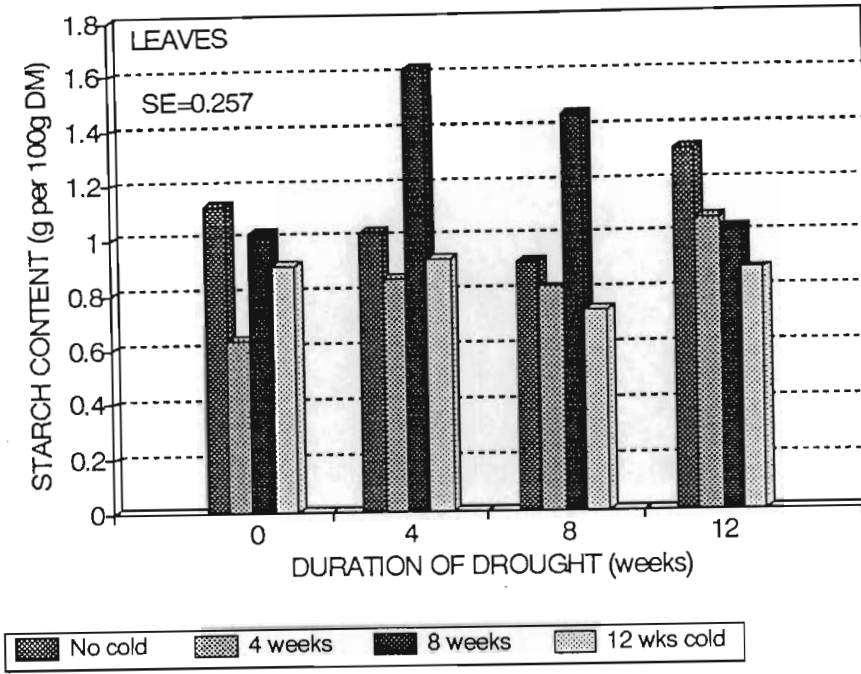


Fig. 4.14

Root starch levels of cashew roots as affected by cold only (A), drought only (B), and the interaction of cold and drought (C).

(A)



(B)

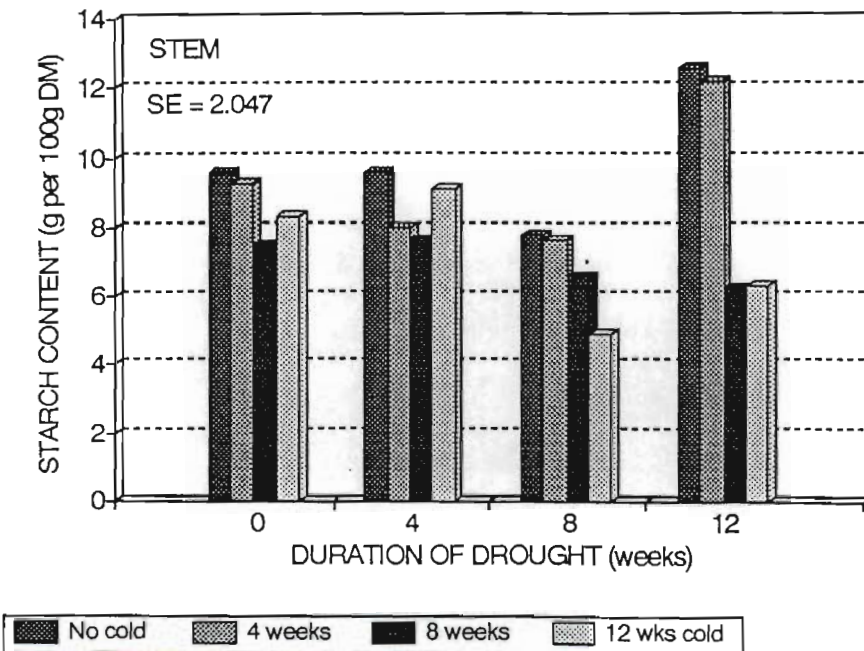


Fig. 4.15 Cashew leaf(A) and stem (B) starch contents as affected by cold and/or drought stress.

4.4 CONCLUSIONS

The main aim of the trial, to study the effects of stress on cashew flowering was not achieved because there was no flowering. The potted trees were either too young to flower under glasshouse conditions, not complex enough to flower, conditions were too conducive to vegetative growth, or trees were too stressed to flower. However, a number of conclusions can be drawn.

It is clear from the data presented that drought, and particularly low temperatures had major effects on cashew trees in a glasshouse. Being drought tolerant tropical trees with a drought-adapting, turgor maintaining latex system, cashews were able to handle drought stress much easier than low temperature stress. This was evident from highly significant decreases in vegetative growth due to cold, while only stem diameter growth was affected by drought. Drought and cold durations had an interactive effect only on early stem diameter growth. Both cold and drought were able to force the growth check necessary for cashew flower induction and synchrony. Permanent damage was not apparent from either drought or cold and therefore both these factors may be used for this purpose in the field, although most places where cashews are grown commercially cold is not a factor.

Drought stress symptoms were noticed about 2 to 3 weeks after soil water potential reached -50 kPa, but no plant physiological parameter could be linked with drought stress symptoms. Leaf water potential was impossible to measure due to high latex content interference, and a critical leaf stress parameter remains to be found. Research into the latex physiology should be undertaken, as it may show promise in this regard.

Regression analysis showed that, in trees receiving either 12 weeks of cold, or 12 weeks of cold and drought combined, transpiration was highly dependent on stomatal conductance. It can be concluded, therefore, that over periods of cold (24/9°C) and drought as long as 12 weeks, the stress effects are dominated by cold rather than drought. In other words, any water applied during that period will not be able to break the stress, because stomatal conductance controls transpiration at these stress levels and the rate of water uptake would not change whether there is an abundance or a shortage of free soil water. Further research into these aspects as well as photosynthesis studies may shed more light on the stress physiology of cashews.

Extreme stress conditions resulted in severe leaf abscission which could be detrimental to growth and flowering following the stress. Dry matter production and total leaf area were also affected by cold. Therefore, cold stress, at the temperatures used, should not exceed a duration of 8 weeks. This is actual plant stress; in the field stress will be imposed on the plant much more gradually than in this glasshouse trial, and this fact is a possible shortcoming of this study as trees will, in all likelihood, react differently with gradual stress being applied.

CHAPTER 5 : EFFECT OF FOLIAR APPLIED UREA ON GROWTH AND FLOWERING OF CASHEW UNDER GLASSHOUSE CONDITIONS

5.1 INTRODUCTION

Stress and nitrogen physiology have been linked to flowering in many plants. According to Lovatt *et al.* (1988), "any stress inhibiting the growth of a plant will result in the accumulation of ammonia (measured as the combined pool of $\text{NH}_3/\text{NH}_4^+$) to an extent directly correlated with the severity or duration of the stress". Four observations suggested that this phenomenon may be related to the induction of flowering in *Citrus* and other tropical and subtropical evergreen trees. Firstly, plants growing in a stressful environment often flower prior to death. Secondly, in tropical and subtropical crops, flowering is promoted by low temperature and water deficit stress. Thirdly, the degree of flowering in *Citrus* is directly proportional to the severity or duration of stress (Southwick & Davenport, 1986). Lastly, nitrogen fertilisation applied at the moment of stress removal enhances the degree of flowering in citrus (Monselise, 1985).

Lovatt *et al.* (1988) also demonstrated that the intensity of flowering could be increased under minimal stress conditions if the ammonia content of the tree was artificially raised by foliar application of low biuret urea. A study was carried out on the effects of urea sprays on cashew seedlings in a greenhouse, and to determine whether the same flowering effects could be achieved on cashews.

5.2 MATERIALS AND METHODS

5.2.1 *Experimental Design and Description of Treatments.*

A randomised blocks factorial design with six replications was used. Four different concentrations (0, 1, 2 and 4 g 100 ml⁻¹) of low-biuret urea were sprayed, either one, two or three times onto the leaves of 18-month old (in May 1990) cashew trees at fortnightly intervals, in order to determine a suitable concentration and number of sprays for inducing or enhancing cashew flowering. The trial was initiated on 26 May 1990. During 1991 the treatments were repeated, starting on 2 May 1991, and a further concentration of 8 g 100 ml⁻¹ of low biuret urea, sprayed once, twice or thrice at fortnightly intervals, was added to the trial. The trial layout is given in Appendix VI.

There was considerable variation in tree size. This was taken care of by arranging the trees in order of size, and dividing the trees into the different replicate blocks. The trees were allocated to treatments within blocks at random, and blocks were given numbers at random. This resulted in significant ($P \leq 0.01$) variation between blocks, but not within blocks or between treatments (CV = 10.41% for initial height, and 7.94 for initial stem diameter) (Table 5.1).

The trees were growing in 20 l pots filled with a mixture of river sand and organic soil (as in 3.1.1 of this thesis). Irrigation was applied through drippers on a daily basis and 30 g 2:3:2 (28) fertilisation was applied to the soil surface bimonthly. One month before treatment application the irrigation was switched off and the soil allowed to dry to a soil tension of -50 kPa, and remain at this level for two weeks. This was to try and force the trees into a reproductive phase.

5.2.2 *Data Collection*

5.2.2.1 Tree Growth

Tree height and stem diameters were measured regularly (approximately every two months) from the start of the trial. Tree height was measured with the use of a tape measure to the nearest cm from the potting soil surface to the top apical bud. Stem diameter was measured using a Mitutoyo^R Digimatic digital vernier calliper, at a marked spot on the stem about 10 cm above the soil surface, in two directions (north-south and east-west). Tree growth was calculated as:

$$(\text{Height (or diameter) at time } t) - (\text{initial height (or diameter)}).$$

Flushing percentage was determined by counting the number of branches flushing compared to the total number of branches.

5.2.2.2 Flowering

The number of panicles per tree, number of flowers per panicle, and the sex ratios of each panicle were determined almost daily.

5.2.2.3 Destructive Harvest

Shortly before the application of the second season's treatment, branch samples 0.8 to 1.5 cm thick were taken for starch analysis. The samples were dried in a forced draught oven at 70°C to constant mass, milled, and analysed for starch content as described in section 3.2.2.

One day after foliar application of urea, two leaves (youngest fully expanded) per tree were sampled, washed in detergent and rinsed in distilled water to remove external urea. These were then dried to constant mass and analysed for $\text{NH}_3/\text{NH}_4^+$ by means of an auto-analyser (full method in Ch. 3). This process was repeated weekly after spraying for 6 weeks after the first trial, and a further sample was taken at the end of the trial.

At the end of the trial all trees were destructively harvested, and fresh and dry mass of leaves, stem and branches, and roots were determined. Total leaf area of each tree was determined using a Licor Leaf Area Meter (LI 3100). The different organs were dried to constant mass, milled and analysed for starch as per section 3.2.2 of this thesis.

5.3 RESULTS AND DISCUSSION

5.3.1 *Visible Response to Urea Sprays*

A concentration of 4% low biuret urea spray scorched the leaves (which were formed under glasshouse conditions and therefore not as thick as field-grown cashew leaves (Plate 4.1)) of the cashew plants. This was visible 12 h after spraying. After 3 days both 2% and 1% urea sprayed trees exhibited scorching of leaves to a lesser extent. The scorching was much worse on these tender leaves grown in a greenhouse than on hardier plants in the field. Some leaf abscission (approx. 10 to 20 % of leaves) took place within three weeks of the third spray of 2 % urea. Urea at 8% concentration resulted in the loss of approximately two thirds of the leaves within two weeks of the first spray, and almost total leaf abscission after the second application. It was therefore clear that this was far too high a concentration for satisfactory cashew tree growth and flowering under glasshouse conditions.

5.3.2 *Tree Growth*

5.3.2.1 Vegetative

Mean growth in height over the first season was 115.52 ± 13.85 cm, and after the second season (1991) 28.03 ± 7.20 cm, the trees exhibiting the typical sigmoidal growth pattern of young trees. There was no significant effect on tree growth by the interaction of urea concentration and number of sprays. However, interaction effects will be discussed, if only to determine trends. Tree height growth was affected significantly by urea concentration. At first there were no noticeable differences in growth rate, but as temperatures increased into summer of 1990 (Fig. 5.1A) the control trees grew rapidly, and during the first year, the control trees grew significantly more ($P \leq 0.01$) (Table 5.1) in height than the other treatments. This was unexpected, because the greater availability of N in the sprayed trees should have made them grow more rapidly. Possibly the sudden shock of the urea sprays may have applied stress to the trees, and therefore slower early growth resulted. The trees sprayed with urea recovered somewhat 3 to 4 months after spray application, and during the 6 month period following, grew more rapidly than control trees. The number of sprays had no significant effect on tree height growth.

During the 1991 season, the trees sprayed with urea grew significantly ($P \leq 0.01$) more than control trees in height (Table 5.1). By this time the trees were much hardier and were able to tolerate and utilize the foliar applied urea, while control trees may have suffered slight N deficiency, since soil N applications were not increased, but maintained at 30 g 2:3:2 (28) every two months. The trees receiving 1 % urea had a similar stem extension growth pattern to controls (Fig. 5.1B), while 2% and 4% urea resulted in significantly greater growth ($P \leq 0.01$) (Table 5.1). During 1991 8 % treated trees initially had similar height growth to controls, but by the end of the trial, the main effects of 8 % urea were significantly higher ($P \leq 0.01$) than controls (Table 5.1). This rapid stem extension growth at the end of the trial was possibly a response by the trees to replace lost leaves after the sprays.

Stem diameter growth displayed similar trends to height growth in 1990, when control trees outgrew the urea-sprayed trees significantly ($P \leq 0.01$) (Table 5.1). The number of sprays, although non-significant, had an effect on stem diameter growth; for every urea concentration in 1990, the growth was slowed down with increasing number of sprays (Fig. 5.2A). This indicated that there was some stress felt by the trees with increasing urea and spray number.

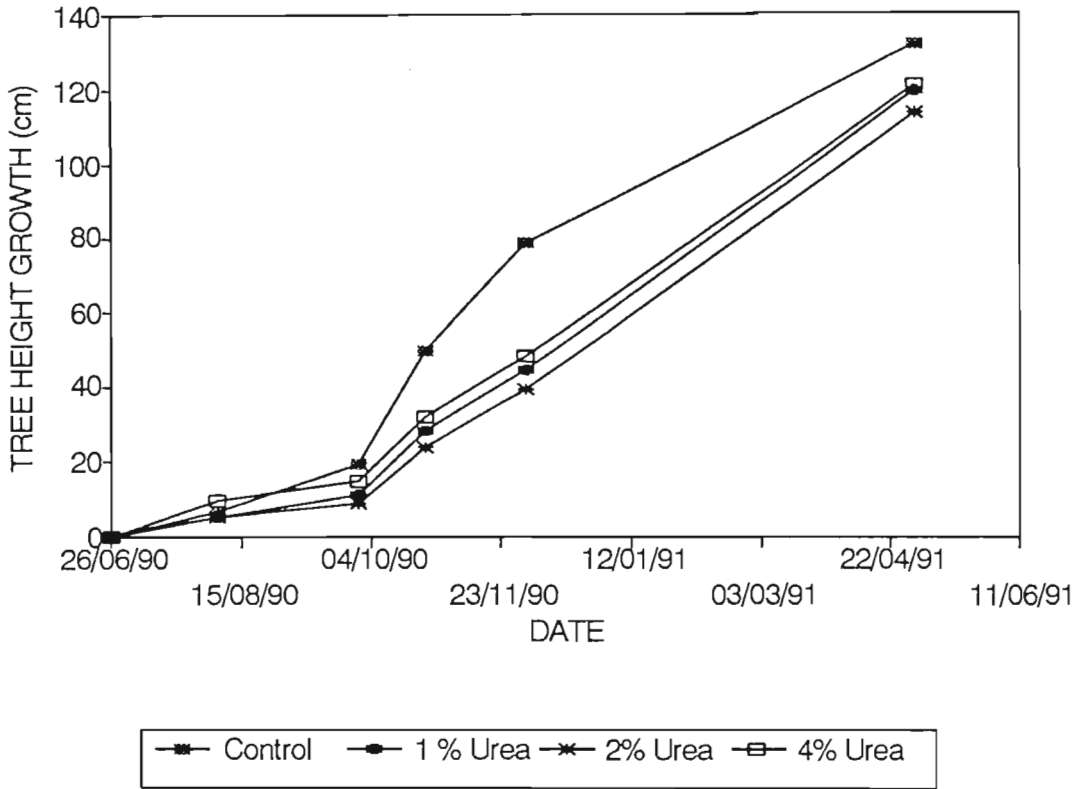
Table 5.1 The main effects of urea concentration on glasshouse-grown cashew tree growth in height and stem diameter. The trees were 18 months old from seed at the start of the trial. Initial dimensions (^z) and growth thereafter are presented.

DATE	LOW-BIURET UREA SPRAY CONCENTRATION					LSD ($P \leq 0.01$)	CV%
	Control	1 %	2 %	4 %	8%		
1990 HEIGHT GROWTH							
26/6/90 ^z	107.7	112.5	114.5	110.4		(NS)	10.41
6/8/90	6.3 ab	5.5 b	5.2 b	9.7 a		3.40	66.31
29/9/90	19.5 a	11.6 bc	9.2 c	15.1 ab		5.31	43.12
25/10/90	50.0 a	28.2 b	23.9 b	31.7 b		8.75	29.13
3/12/90	78.7 a	44.8 b	39.1 b	48.2 b		15.66	33.25
STEM DIAMETER							
26/6/90 ^z	19.09	17.89	18.80	19.76		(NS)	7.94
6/8/90	1.76 a	1.06 b	0.80 b	0.69 b		0.393	40.80
29/9/90	4.14 a	3.00 b	2.46 bc	1.95 c		0.753	29.30
25/10/90	5.95 a	4.65 b	3.95 bc	3.47 c		0.957	23.88
3/12/90	7.76 a	6.28 b	5.43 b	5.05 b		1.380	25.32
1991 HEIGHT GROWTH							
2/5/91 ^z	239.5	228.2	231.6	231.6	202.7		14.97
3/7/91	2.3 b	4.7 ab	9.9 a	8.6 ab	4.9 ab	7.29	136.11
16/9/91	7.8 c	10.2 bc	18.4 ab	19.9 a	14.4 abc	8.75	70.23
20/11/91	18.2 c	19.3 bc	31.3 abc	34.7 ab	36.6 a	15.54	62.94
STEM DIAMETER GROWTH							
2/5/91 ^z	31.88	30.08	29.99	30.26	26.12		11.29
3/7/91	1.04 a	1.44 a	1.18 a	1.01 a	-0.1 b	0.574	71.33
16/9/91	2.03 a	2.71 a	2.34 a	2.41 a	-0.01 b	0.810	48.59
20/11/91	4.43 a	4.79 a	4.33 a	4.75 a	1.42 b	1.489	42.86

^z Initial height or stem diameter dimensions.

^y Treatment means in the same row with letters in common are not significantly different at the 1% probability level.

(A) 1990



(B) 1991

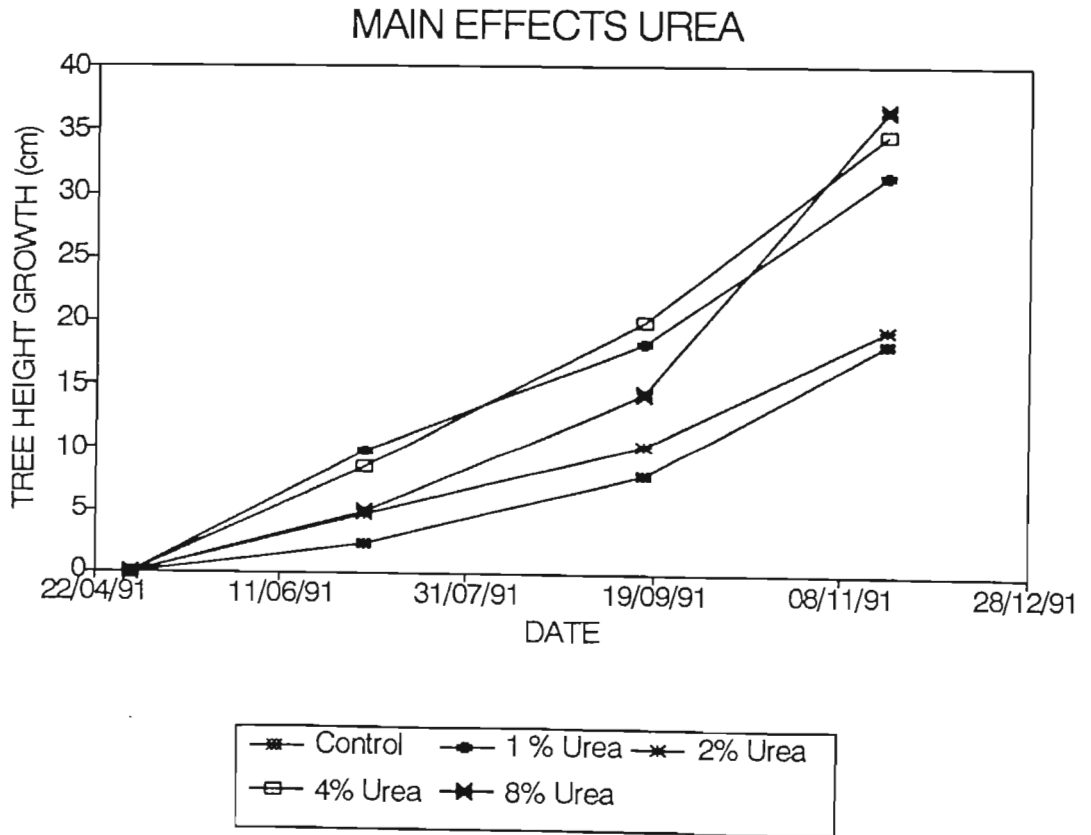
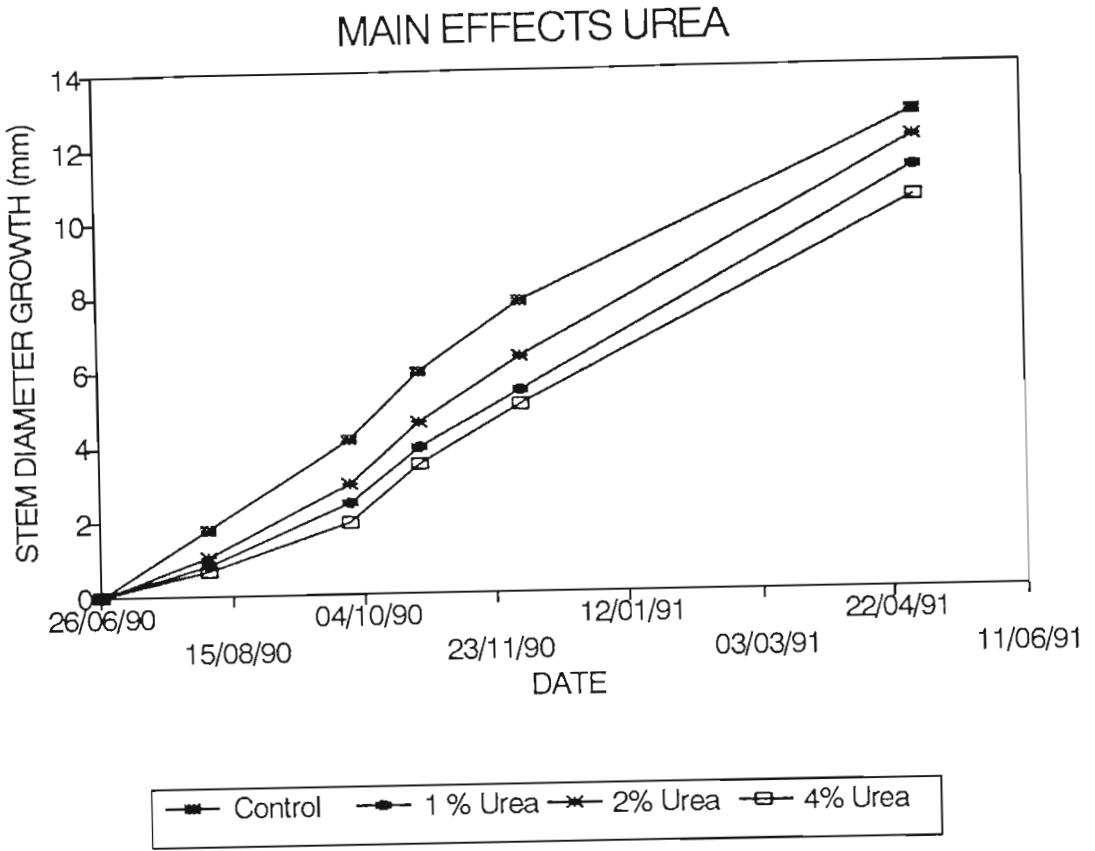


Fig. 5.1.

Stem extension growth during 1990 (A) and 1991 (B), as affected by one two or three foliar applications of different low-biuret urea concentrations.

(A) 1990



(B) 1991

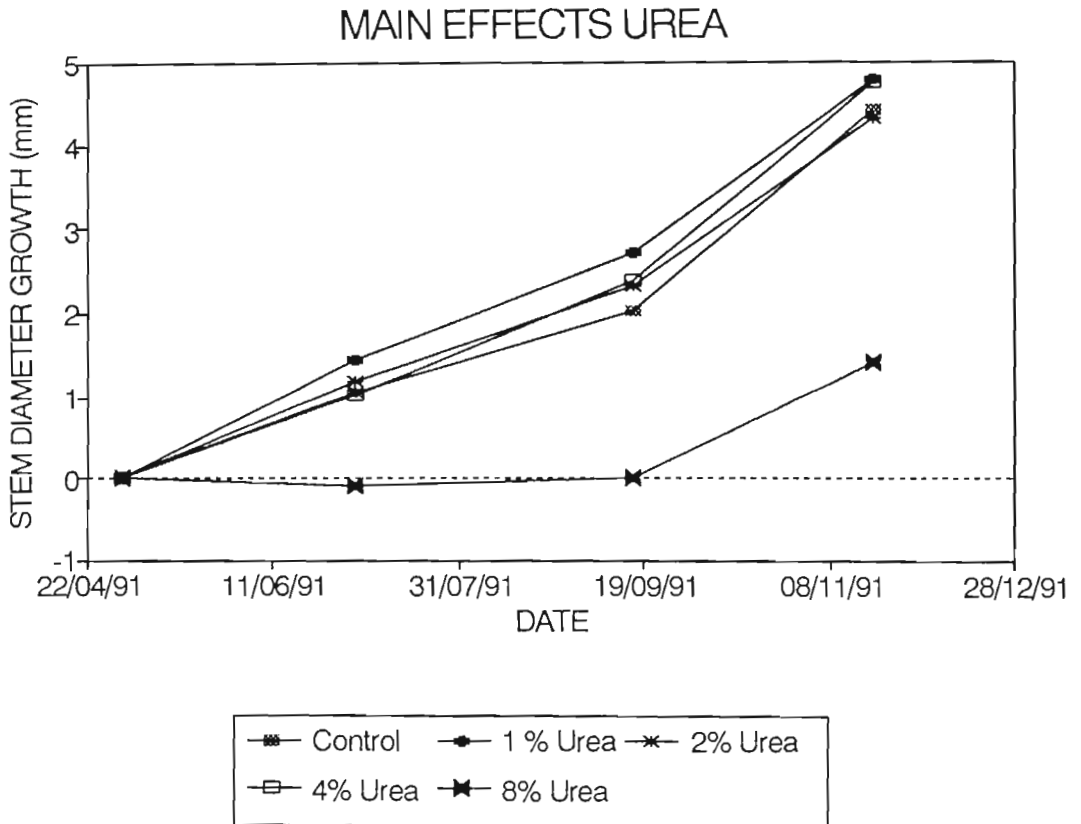


Fig. 5.2.

Stem diameter growth during 1990 (A) and 1991 (B), as affected by one two or three foliar applications of different low-biuret urea concentrations.

During 1991, the most interesting effects on stem diameter were obtained. The trees sprayed with 8% urea grew highly significantly less ($P \leq 0.01$) than all other urea concentrations, which were not significantly different to each other at this level of probability (Table 5.1). The 8% treated trees had a mean negative growth in stem diameter, indicating possible mass movement of stored carbohydrates from the stem. The carbohydrates could have been used for two (or more) purposes: firstly, for growth in height which was significantly greater than control height growth, and secondly for carbohydrate energy to detoxify the $\text{NH}_3/\text{NH}_4^+$ build-up in the remaining leaves. There was a period of rapid growth five months after urea application, which was a possible indication of the time taken for detoxification sufficient for normal growth. The trees sprayed three times with 8% urea never recovered during the trial (Fig. 5.2B).

Tree flushing was measured only during the second season, and was affected significantly ($P \leq 0.01$) by urea concentration but not by number of sprays. At commencement (2/5/91), there were no significant differences in flush percentage between spray concentrations. Two months afterwards, however, the trees sprayed with urea had significantly higher ($P \leq 0.01$) flushing percentage than controls, which had c. 30% flushing (similar to flushing % at the start) (Fig. 5.3). This flushing is reported to be desirable in cashew since cashew flowers on young wood following a post dormancy flush, although some trees have been observed flowering on mature wood from the previous season's post harvest flush (Ohler, 1979). Two months later, there were no significant differences between urea concentrations as far as flushing was concerned, and this remained so at the end of the trial (Fig. 5.3).

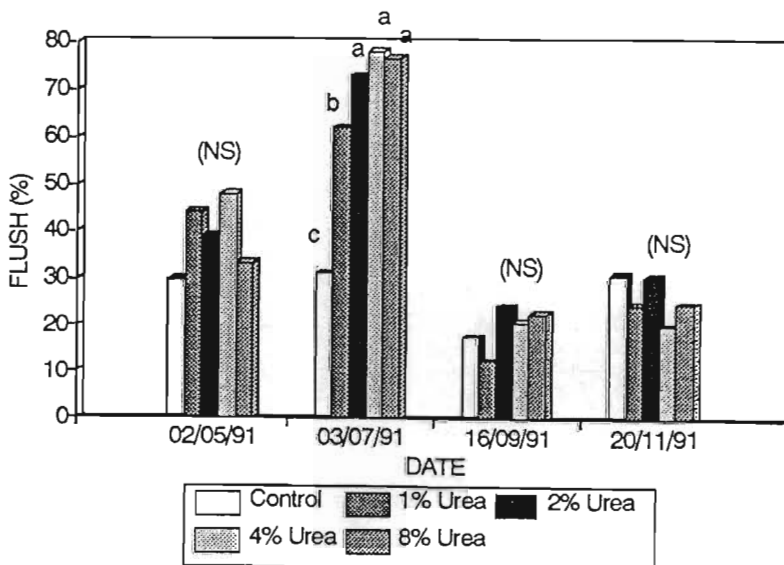


Fig. 5.3 Flushing of cashew trees in response to different concentrations of foliar-applied urea. Bars in one date with the same letter are not significantly different ($P \leq 0.01$).

The higher flushing activity of the urea treated trees also resulted in a higher branch number, and hence

tree complexity than control trees (Fig 5.4A.). The higher concentrations (4 and 8 %), and the triple application of all concentrations of urea resulted in sucker development on the main stem (Fig. 5.4B). This was particularly prevalent on the trees receiving 4 and 8% urea which lost a large proportion of leaves. This production of succulent shoots is typical of plants which have excess N available to them (Tisdale *et al.*, 1985). Another possibility is the stress-induced loss of apical dominance, resulting in excessive suckering. The trial did not carry on long enough to determine the growth and possible flowering from these suckers. However, it was noticed that the trees which flowered did not produce these suckers, and it was therefore speculated that they were produced at the expense of flowering, or that the trees displaying stem suckering were simply too vegetative to flower.

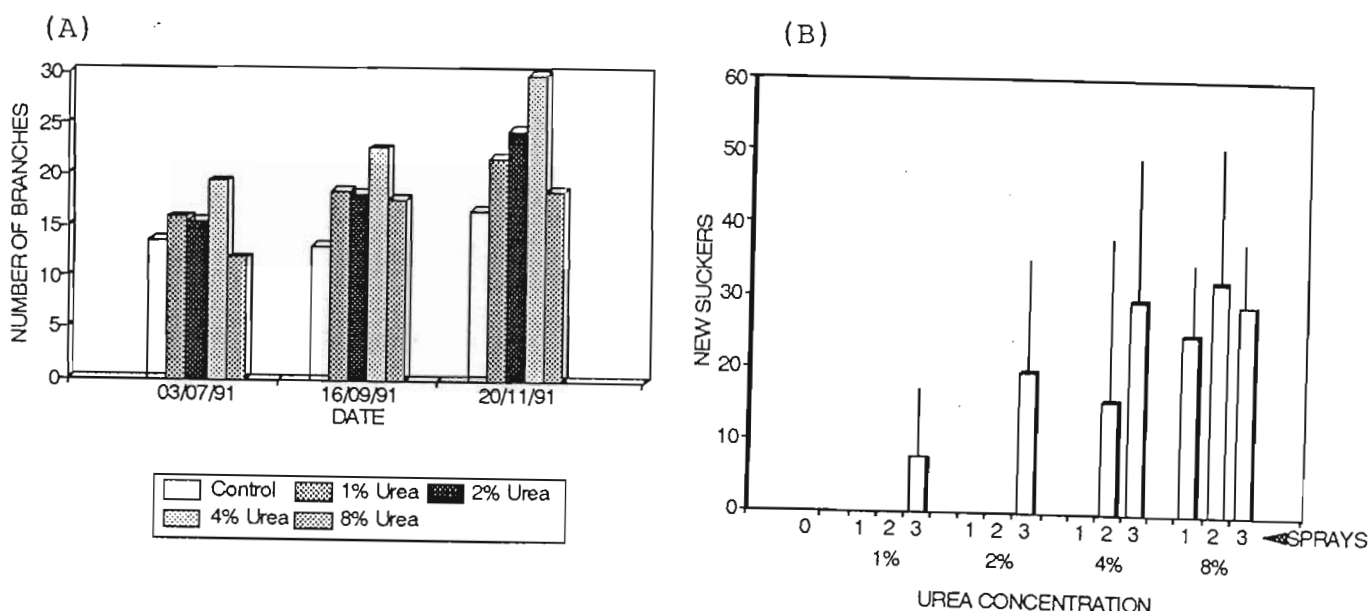


Fig. 5.4. The number of branches (A) and vegetative suckers from the stem (B) of cashew trees sprayed with different concentrations of urea.

5.3.2.2 Flowering

A single panicle was produced during the first year, on a tree receiving two applications of 4% urea. During the second season only seven trees flowered. This made statistical analysis between treatments impossible. However some interesting results were obtained. On the solitary panicle of the first year the flowers were counted and their sex recorded. It was noticed that the first flower to open was the terminal flower of the rachis, and this was hermaphrodite. The terminal flowers on the distal panicle branches opened next, these also being hermaphrodites. The flowers along the panicle branches opened from the distal end, proceeding basipetally, and were mostly hermaphrodite, the first male flowers being noticed some 16 days after first anthesis. During the second year, the same trends were noticed on 20

panicles (Fig. 5.5 A;B). Male flowers were recorded in much more distal positions along the panicle branches, and opened much earlier than the single panicle of the previous year. These results are in agreement with Ashok (1979) and Subbaiah (1983), who attributed this basipetal anthesis and sex expression to the basipetal gradient of endogenous auxin concentration in the shoot apex of the panicle.

The flowering patterns observed in this trial started out with 76.8% mean hermaphrodite:male ratio which will be termed the hermaphrodite phase. The mixed male and hermaphrodite phase started 20 days after first anthesis, when the male flower numbers exceeded the number of perfect flowers. The mixed phase then started with 47.5% perfect flowers which decreased to 32.7% 45 days after first anthesis. After this the hermaphrodite flower percentage varied from 30 to 53%. At no stage was there a purely male phase. These results contradict Pavithran & Ravindranathan (1974) who reported three flowering phases: a short male phase, followed by a mixed male and hermaphrodite phase, and finally a male phase. Wunnachit & Sedgley (1992) also found that more than 90 % of the hermaphrodite flowers opened between weeks one and three after flowering started. They did not find as high a hermaphrodite percentage (22.1 % maximum) as in this study (76%), but their study was in the field, which probably accounts for these differences.

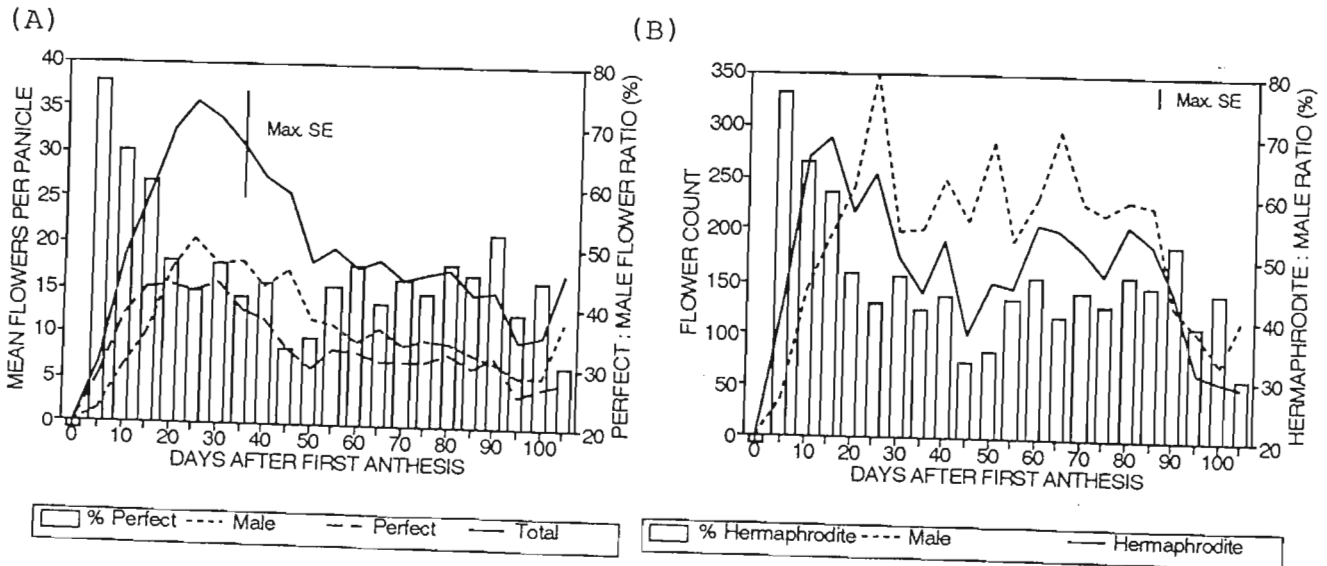


Fig 5.5. Mean flower counts per panicle (A), and total flower counts of all panicles (B) in a glasshouse trial to test the effects of urea concentrations on flowering.

Due to the low number of trees flowering, only a few trends could be observed. All the trees which flowered received either two or three urea sprays; neither control trees nor those receiving a single spray flowered (Fig. 5.6). The treatment with the highest percentage (50%) of flowering trees was that

receiving 3 sprays of 2% urea. All the other treatments for which flowering was recorded had only one tree (out of a possible six) flowering; hardly convincing evidence. However, there was an indication of three 2% sprays being in the optimum range; all the flowering treatments are close to this highest flowering treatment. This could have been an optimum treatment, with higher and/or lower concentrations, or fewer sprays, providing a less optimum, or lower, flowering stimulus. These results may have been purely by chance as no statistically based evidence can be shown.

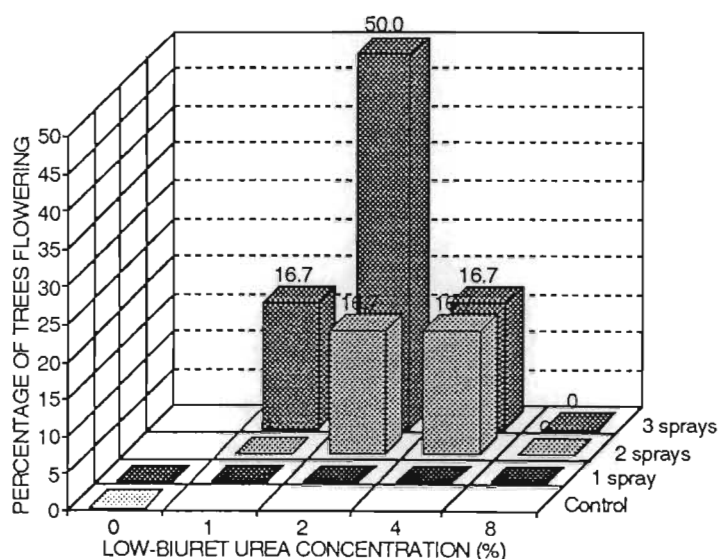


Fig. 5.6 Percentage of trees sprayed with different urea concentrations flowering.

5.3.3 Leaf $\text{NH}_3/\text{NH}_4^+$ Levels

The youngest fully expanded leaf was analysed for $\text{NH}_3/\text{NH}_4^+$ content one day before the trial commenced, and one day, and one week, after each spray application. Urea spray at 1% concentration resulted in an increase of leaf $\text{NH}_3/\text{NH}_4^+$ from $22 \mu\text{g g}^{-1}$ DM to $220 \mu\text{g g}^{-1}$ DM one day after spraying (Fig. 5.7A). In trees receiving only one spray at this concentration, the leaf $\text{NH}_3/\text{NH}_4^+$ dropped to below $100 \mu\text{g g}^{-1}$ after 7 days, and after 22 days decreased to $25.7 \mu\text{g g}^{-1}$, a level similar to the control trees. In the leaves of trees receiving a second spray, the ammonia levels increased to over $100 \mu\text{g g}^{-1}$ one day after the second spray, but these decreased to levels similar to the control, 14 days after the second spray (28 days after start). Trees receiving three sprays (at 1%) had leaf $\text{NH}_3/\text{NH}_4^+$ levels of about $100 \mu\text{g g}^{-1}$ for longer than a month, but by the end of the trial the level had decreased to $46.8 \mu\text{g g}^{-1}$. It appeared that the cashew trees were able to tolerate and utilise 1% urea with no real problems, except possibly after three sprays.

One day after the first 2% urea sprays the leaf $\text{NH}_3/\text{NH}_4^+$ concentration increased to over $200 \mu\text{g g}^{-1}$

DM, and dropped to 100 to 150 $\mu\text{g g}^{-1}$ within a week (Fig. 5.7B). After the second and third sprays the levels increased to over 200 $\mu\text{g g}^{-1}$ DM, but in each case the mechanisms for ammonia detoxification were able to reduce the $\text{NH}_3/\text{NH}_4^+$ levels. Leaf ammonia levels were above 100 $\mu\text{g g}^{-1}$ for more than 1 month in trees receiving two and three sprays of 2 % urea.

At a concentration of 4% urea, the leaf $\text{NH}_3/\text{NH}_4^+$ levels were about 300 $\mu\text{g g}^{-1}$ DM after one day, and this increased to 800 and 600 $\mu\text{g g}^{-1}$ after two and three sprays respectively (Fig. 5.7C). The leaves were clearly not able to detoxify the $\text{NH}_3/\text{NH}_4^+$ satisfactorily, and there was a high leaf abscission rate at this concentration. It took three weeks to detoxify the leaves after a single spray, and only by the time of destructive harvest (157 days after spraying) had the leaf $\text{NH}_3/\text{NH}_4^+$ levels of trees sprayed twice or thrice decreased to below 100 $\mu\text{g g}^{-1}$.

Eight per cent urea had a detrimental effect on cashew leaves. The leaf $\text{NH}_3/\text{NH}_4^+$ concentration increased to extremely high levels, and the trees receiving more than one spray lost so many leaves that there were not sufficient to complete the analysis for these treatments. The new leaves which emerged after leaf abscission had a concentration $< 100 \mu\text{g g}^{-1}$ $\text{NH}_3/\text{NH}_4^+$. It took between 43 and 157 days to reduce the $\text{NH}_3/\text{NH}_4^+$ levels to below 200 $\mu\text{g g}^{-1}$.

With the exception of the 8 % treated trees, the leaf $\text{NH}_3/\text{NH}_4^+$ levels of all the treatments had decreased to levels below 100 $\mu\text{g g}^{-1}$ DM by the time of destructive harvest approximately 5 months later. Therefore there was no long term effect on the trees. At 1% and 2% urea application the decrease to below 100 $\mu\text{g g}^{-1}$ DM took less than a month. This was in agreement with Ali & Lovatt (1992), and Rabe & van der Walt (1993) who found similar results on citrus after foliar urea application. All the treatments that flowered had leaf $\text{NH}_3/\text{NH}_4^+$ levels of between 100 and 700 $\mu\text{g g}^{-1}$ for about a month, and perhaps, if there is one at all, the critical level to stimulate flowering lies within these extremes in leaf $\text{NH}_3/\text{NH}_4^+$ concentration, over approximately one month. A deeper study into the nitrogen stress physiology of cashew is necessary to try to find any definite link between leaf ammonia and flowering in cashews, but bearing in mind the small size of the potted seedlings, there were indications that urea sprays may have potential to manipulate cashew flowering.

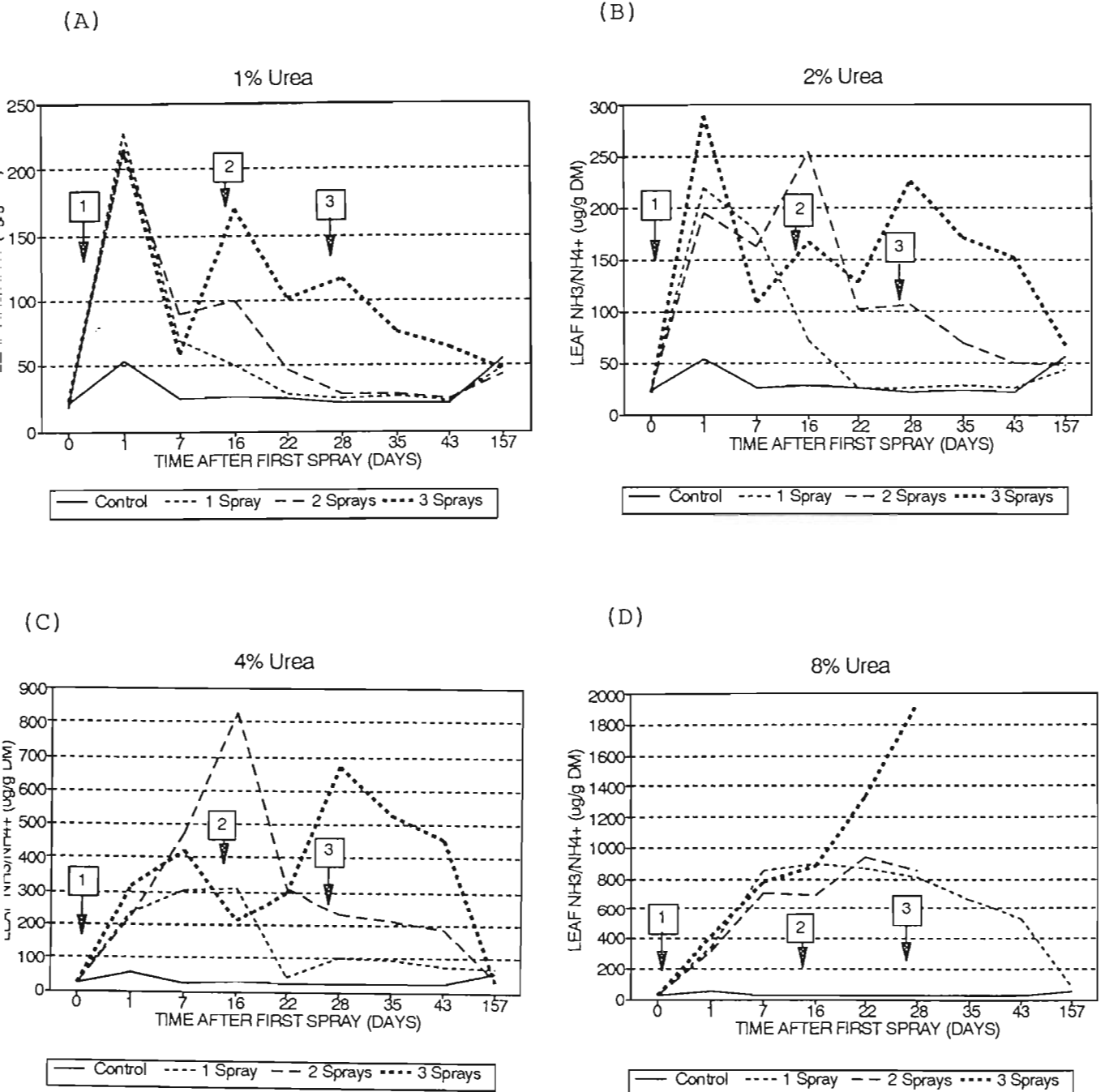


Fig. 5.7. Leaf $\text{NH}_3/\text{NH}_4^+$ levels of glasshouse-grown cashew trees sprayed with 1% (A), 2% (B), 4% (C) and 8% (D) low biuret urea. Numbers in blocks indicate timing of the three sprays

5.3.4 Starch Levels

During April 1991, prior to the 1991 season's urea applications, hardened branches 0.5 to 1.5 cm thick were sampled and analysed for starch. There appeared to be a carry-over effect from the previous season's urea sprays (Fig. 5.8A). The controls and 1% urea-applied trees, which grew more than the other urea treated trees during 1990, had relatively low starch levels (3.0 to $3.4 \text{ g } 100 \text{ g}^{-1}$) compared to the 2% and 4% urea treatments. The high N levels from the urea sprays were likely to have improved photosynthetic efficiency of the urea-sprayed trees, and hence a greater proportion of assimilates were stored. The 8% trees were not used during the first year, but their starch levels ranged from 3.81 to $4.92 \text{ g } 100 \text{ g}^{-1} \text{ DM}$.

Leaf starch levels on 20/11/91 (the date of destructive harvest) ranged from $0.78 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ to $1.04 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ (Fig. 5.8B), and there were no significant differences between treatments. Starch levels in the roots and stem were affected highly significantly ($P \leq 0.01$) by urea concentration. The starch in stems of 8% trees was significantly lower ($P \leq 0.01$) than the 0%, 1% and 4% urea-sprayed trees (Fig. 5.8C), and the root starch of the 8% treatment was significantly lower ($P \leq 0.01$) than the rest of the treatments (Fig. 5.8D). This was a possible indication of starch mobilisation from the stem and roots to supply energy and carbon for nitrogenous molecules produced in the process of ammonia detoxification in the leaves of these trees (Salisbury & Ross, 1978; Rabe, 1990).

5.3.5 Destructive Harvest

On 20 November 1991 the trial was destructively harvested, divided into the respective plant organs, dried and weighed, and leaf area determined. Urea concentration affected most of these parameters significantly ($P \leq 0.01$) (Table 5.2). The leaf, stem and root dry masses of the 1%, 2% and 4% urea sprays were significantly greater than the control and 8% urea treatments. This indicated the production of biomass which resulted from the middle three concentrations. These data display the typical plant nutritional phenomena of nutrient deficiency at low levels, a plane of nutrient sufficiency (a range at which plants grow well), and nutrient toxicity. The control did not receive sufficient N for such rapid growth, while the highest urea concentration was in the toxicity level and therefore used much of the energy needed for growth, or detoxification of ammonia.

A detailed explanation of the mechanisms involved in leaf ammonia detoxification due to environmental stress was given by Rabe (1990). A number of nitrogen-containing compounds (NCC) accumulate in plants when subjected to stress. The functions of these NCC's are diverse (cytoplasmic osmoticum; hydration of biopolymers; serve as a readily utilisable energy and N source; etc.). One of the important NCC's accumulating in stressed plants is arginine. The arginine *de novo* biosynthetic pathway provides a mechanism for detoxifying leaf tissue of excess ammonia. This *de novo* pathway is expensive in terms of ATP and carbon but it "mops up" $\text{NH}_3/\text{NH}_4^+$. Although arginine was not measured in this trial, the low

starch levels detected in the trees receiving 8 % urea sprays may have been caused in this manner.

The greatest mean leaf area was produced by the 2% urea treatment, which was highly significantly greater ($P \leq 0.01$) than the rest of the treatments (Table 5.2). The root : shoot ratios were statistically similar, indicating that the vigour or lack thereof was reflected in the organs above and below the soil. Approximately half the dry matter production was below the soil. Mean leaf size (on a mass and leaf area basis) of trees receiving 2% urea was also significantly higher than all other treatments. This was further evidence of the optimal nature for growth of 2% urea foliar sprays under the conditions of the trial.

Table 5.2. Main effects of urea concentration on different parameters at final destructive harvest.

Urea concentration	Dry Mass (g)			Leaf Area (cm ²)	Leaf number	Root: shoot ratio	Leaf size	
	Leaf	Stem	Root				(mg DM leaf ⁻¹)	(cm ² leaf ⁻¹)
Control	93.17 b	377.5 a	194.8 a	9754.2 c	300.7abc	0.52 a	444.2 b	41.06 c
1%	168.1 a	387.0 a	191.4 a	18281.0 b	319.0 a	0.51 a	696.4 b	69.47 b
2%	181.3 a	400.2 a	188.4 a	19914.0 a	209.7 c	0.49 a	1122.4 a	108.53 a
4%	175.3 a	436.0 a	201.3 a	18566.2 b	303.6 ab	0.46 a	686.2 b	68.74 b
8%	93.7 b	231.7 b	107.0 b	9829.7 c	219.0 bc	0.49 a	510.8 b	50.60 bc
LSD ($P \leq 0.01$)	28.9	72.79	29.92	892.8	92.19	0.068	297.2	25.91
CV%	23.00	22.50	19.20	20.84	38.63	15.11	48.66	43.37

Note: Means in the same column with symbols in common are not significantly different ($P \leq 0.01$).

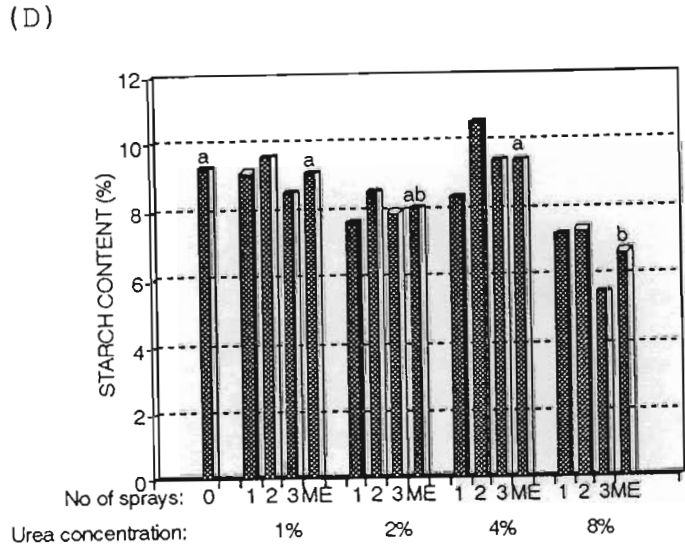
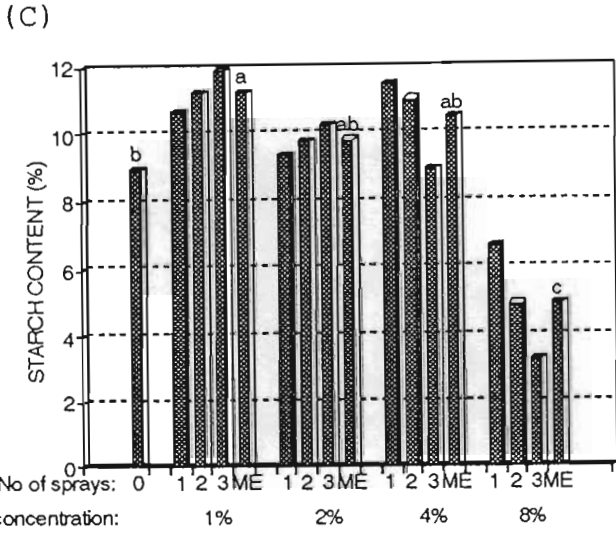
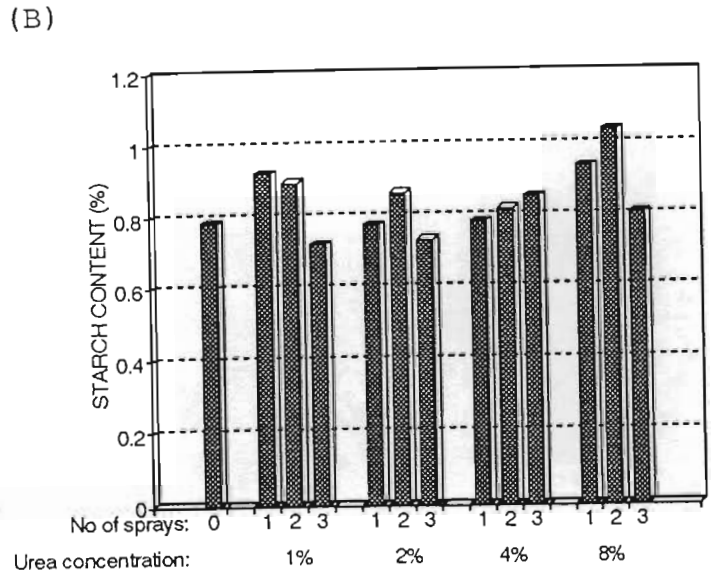
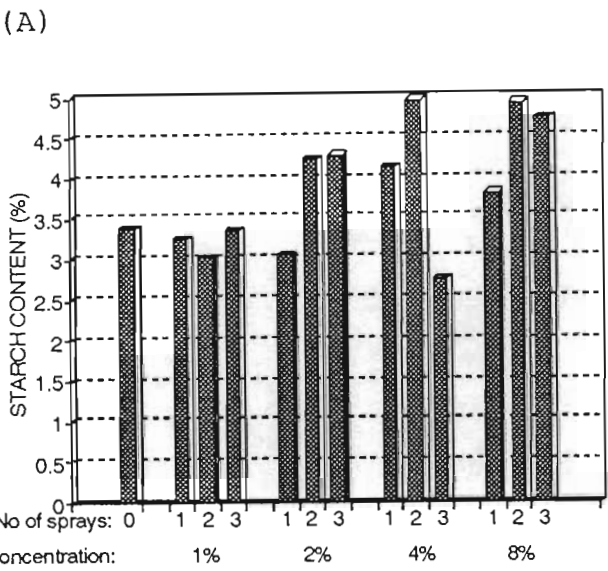


Fig. 5.8. Starch levels of branches 0.5 to 1.5 cm in diameter prior to urea application in May 1991 (A), and starch levels of leaves (B), stems (C) and roots (D) at destructive harvest. ME represents the main effect of the urea concentration. Main effect means sharing the same letter are not significantly different ($P \leq 0.01$).

5.4 CONCLUSIONS

It was not possible to fully achieve the main objective of this trial, viz. to investigate the effects of urea on flowering, fully because only a small proportion of the trees flowered. However, there were some conclusions to be drawn from the few trees which did flower.

Flowering started out with a hermaphrodite phase followed by a mixed male/hermaphrodite phase, the male flower percentage becoming increasingly higher over time, which was in contrast to some reports. A reported basipetal flower production and basipetal increase in flower maleness was confirmed. Abnormally high hermaphrodite flower percentages were attributed to optimum glasshouse conditions.

Conclusions on optimum urea spray concentrations and numbers were difficult to come to. The most vigorous growth, dry matter production, highest leaf area, largest individual leaves, highest branch number and complexity, and greatest number of flowering trees were obtained after 2% urea application. The treatments which flowered had leaf $\text{NH}_3/\text{NH}_4^+$ levels $\geq 100 \leq 700 \mu\text{g g}^{-1}$ DM for about one month, and it is therefore suggested that the management of cashew trees should be aimed at producing leaf $\text{NH}_3/\text{NH}_4^+$ within this range. Management includes foliar urea sprays and other stress treatments to increase leaf $\text{NH}_3/\text{NH}_4^+$ for about one month. The urea concentrations and number of sprays for field applications may differ, and therefore such trials will have to be repeated under field conditions.

One conclusion that can be made without too much doubt is that more than one spray of 8% urea was detrimental to tree growth and vigour and carbohydrate physiology under the conditions of the trial, and cannot be recommended. Although no sound recommendations could be made about the use of urea sprays for flower manipulation, it can safely be said that foliar N application is an efficient and rapid means of getting N into the leaf for nutrition purposes; increases being noticed one day after application. Young potted seedling trees of the size used proved to be difficult to force into flowering under greenhouse conditions, but the fact that some trees did respond to urea sprays was encouraging.

Future research should include field evaluation of foliar applied urea using bearing clonal trees. Photosynthesis studies together with starch analysis will give a good idea of the source (leaf) - sink (carbohydrate users) relationships.

CHAPTER 6: EFFECT OF WITHHOLDING IRRIGATION AND GIRDLING ON CASHEW TREES IN MAPUTALAND

6.1 INTRODUCTION

There are basically two types of tree manipulation, physical and chemical. Chemical tree manipulation has been used for some time, but is slowly losing popularity because of environmental damage/pollution, in some cases toxicity to humans, animals and/or plants, environmentalist lobby groups in developed countries, economic non-viability, etc. On the other hand, physical tree manipulation such as withholding irrigation water, root and canopy pruning, and girdling *inter alia*, is becoming more popular because of its environmentally friendly image, particularly to wealthy, "first world" consumers.

From the literature (Ohler, 1979; Wait & Jamieson, 1986) and from observations in Maputaland it was determined that approximately six weeks of drought stress was sufficient for flower induction. The timing of flowering is strongly influenced by temperature and observations in Maputaland have shown that cashew trees start flowering when mean temperatures in spring exceed about 24°C (Staples, undated). At Makatini Research Station, in Maputaland (Appendix I), minimum winter temperatures can be as low as 1°C for short periods, and this indicates the marginality of this area for commercial cashew cultivation. Cold stress has generally been considered to be detrimental to cashew trees (Ohler, 1979). However, cashew cultivation normally takes place within the tropics, and these areas rarely experience regular annual cool periods. A question to answer is whether regular cool periods are always detrimental, or whether they may be beneficial in some way to cashew trees. The author saw some mature (20+ years) cashew trees which were looking quite healthy at Makatini Research Station, despite experiencing regular winter cold spells.

Taking these facts into account, it was decided to investigate the influence of a two month dry period at different times during winter, and to find out, firstly, whether there was any influence of the **timing** of drought stress on growth, flowering and yields of cashew trees in Maputaland, and secondly, whether cool winter temperatures could replace or enhance the drought stress effects on flower induction and synchrony at Makatini Research Station.

Girdling has long been known to increase flowering and yields, much of the work having been done on temperate fruit trees and citrus, and has been reviewed by Noel (1970) and Cohen (1981). The use of girdling to reduce vigour, and increase flowering and yields has never been studied on cashew (Schaper & Chacko, 1993).

As many factors are influenced by girdling, it is difficult to determine which are causes and which are

effects. The mode of action behind girdling may be explained in terms of changes in the hormone balance (Wallerstein, Goren & Monselise, 1973; van Staden & Brown, 1978) and carbohydrates (Monselise & Goldschmidt, 1982; Goldschmidt *et al.*, 1985). A secondary aim, of much lesser importance to the primary aim of this trial, was to observe the effects of girdling on flowering, growth and yields of cashew trees in Maputaland.

6.2 . METHODS AND MATERIALS

An irrigated, four-year-old cashew orchard, consisting of 196 trees grown from seed, was made available at Makatini Research Station for this trial. The orchard was irrigated by micro-jet system. Trees were planted at 10 x 10 m and growing in regic sandy soil (Fernwood form). A randomised blocks design with five trees per plot, five plots per block, and five blocks (Appendix VII), was utilised. Irrigation was stopped for a period of two months during autumn and winter. The treatments were as follows:

1. Drought from 1 May to 30 June
2. Drought from 1 June to 31 July
3. Drought from 1 July to 31 August
4. Drought from 1 August to 30 September
5. Control; did not receive any drought stress (fully irrigated).

Tree height, canopy diameter, and trunk girth growth were determined biennially. Flowering was rated for two seasons, flower bud production (on the basis of % unopened buds) and flushing were visually rated by estimating the percentages of these events. These estimations were subjective ratings, based on 10 to 20 randomly selected branches per tree, only on the northern side, because the southern sides of the trees used in this trial grew and flowered erratically. Total yield per tree was determined for both seasons, but during the second season, the yield distribution over time was also determined. Bark samples of one tree per treatment were taken on 25 September 1991 and analysed to see whether the treatments had any effect on starch storage over winter. Leaf samples were taken to determine leaf $\text{NH}_3/\text{NH}_4^+$ and see whether this affected flowering.

During 1990 it was decided to determine the effects of girdling on growth, flowering and yields of cashew trees, in another attempt to manipulate these trees by physical methods. Unfortunately the only trees available for such a study were the border rows of the drought stress trial at Makatini Research Station; no randomisation could be done, and therefore the trial could only be classed as an observation trial (statistically non-analysable). Only trees experiencing a drought stress period during June and July were considered. Normal agricultural practices (fertilizers, skirting, weed control, fungicide sprays, etc.) were applied to all trees.

The tree trunks were girdled using girdling knives and a sharp knife (for the narrowest cincture) about

25 cm above ground level. This trial was started on 12 March 1991 and ran until the harvest of that season was complete in April 1992. Five replicates of seven single tree plots were used (Table 6.1). Half the trees were girdled (three different widths) in March 1991 to try to discourage excessive vegetative growth of the post-harvest flush, thereby decreasing the use of reserves for vegetative growth. The other half of the trees were girdled in May 1991 to try to influence flower induction and the preflowering flush.

Table 6.1 Treatments used in a girdling observational trial at Makatini Research Station.

Treatment Number	Time of Girdling	Girdle Width
0	Control	No Girdle
11	12 March 1991	Knife cut cincture
12	12 March 1991	4 to 5 mm
13	12 March 1991	8 to 10 mm
21	26 May 1991	Knife cut cincture
22	26 May 1991	4 to 5 mm
23	26 May 1991	8 to 10 mm

6.3 RESULTS AND DISCUSSION

6.3.1 Climatic data

The mean temperatures during both the 1990/91 (Fig. 6.1A) and 1991/92 (Fig. 6.1B) seasons were below 20°C during the period from May to September, the period of drought stress treatments. The mean monthly minima during this period varied from 9.0 to 15.9°C. Rainfall during the 1990/91 season (Fig. 6.1A) was low (43.6 mm total from May to September), but during the following season (Fig. 6.1B) there was high unseasonal rainfall during May, taking the total rainfall during May to September up to 225.3 mm, which influenced the treatments, most notably the trees receiving no irrigation during May and June, and June and July. There were large deficits between rain and A pan evaporation during the treatment period of the first season (Fig. 6.2A), but during the 1991/92 season, there was a water surplus during May and small deficits during June and July. This should be taken into consideration when viewing data from the two treatments receiving drought stress during these three months.

Of interest is the large water deficit throughout most of the rest of the year, except the wettest months. This indicates that, for optimum management and production in Maputaland, either there must a supplementary irrigation system, or the water table must be within about 2.5 to 5 m below the soil surface, so that water is freely available for use by the tree. This is particularly so during the sensitive flowering and fruit set stages, which for cashew in this region can span about 4 months. The added expense of an irrigation system, however, may make cashew economically unviable in areas of

Maputaland where the water table is deeper than 5 to 10 m.

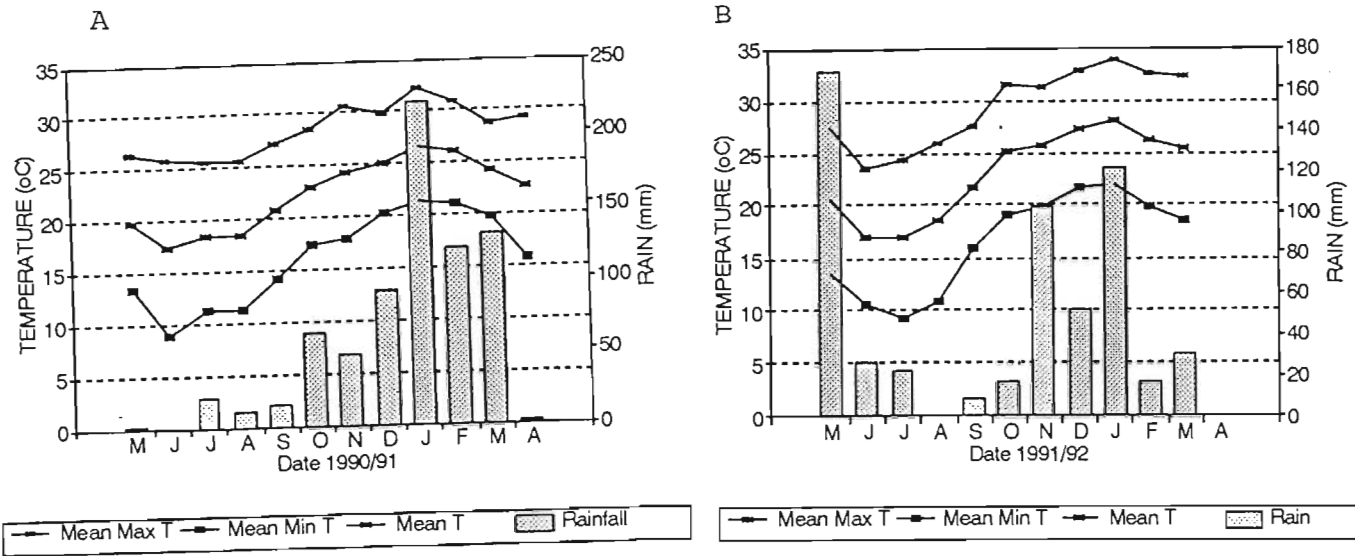


Fig. 6.1 Monthly mean maxima, minima and total rainfall for A 1990/91, and B 1991/92 at Makatini Research Station.

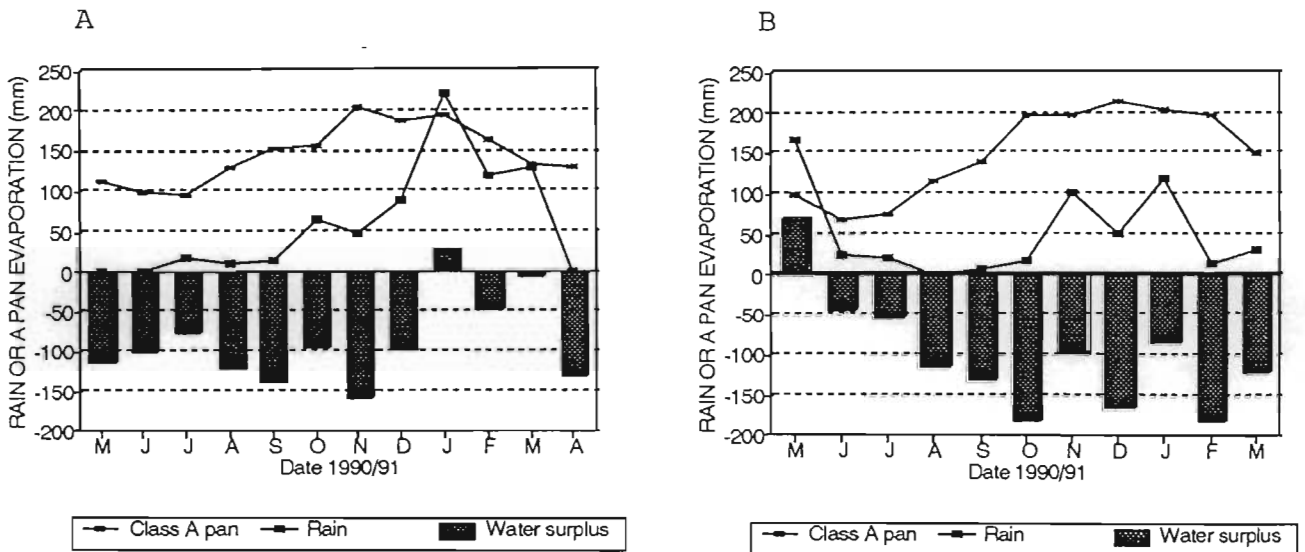


Fig. 6.2 Total monthly rainfall in relation to total monthly A pan evaporation at Makatini Research Station for: A 1990/91, and B, 1991/92. Bars represent the monthly water surplus or deficit.

6.3.2 Water Deficit Trial

6.3.2.1 Vegetative Growth

Cashew trees in this trial increased their mean height by 1.187 m, canopy diameter by 1.721 m, and trunk girth by 19.031 cm in just under two years. This indicates the high growing vigour of cashew trees, even in areas considered to have a marginal climate. Tsakiris (1967) reported growth rates of approximately 1 m year⁻¹ in height, and 1.5 to 2.0 m year⁻¹ in canopy diameter in Tanzania, a more ideal growing climate than Maputaland. Therefore at Makatini Research Station, the average annual growth rate was about half that in Tanzania.

Changing the drought stress period over the 'dormant' winter period had very little effect on the growth (change in dimensions) of cashew trees in Maputaland. There were no significant differences between treatments, as far as height (Fig. 6.3), canopy diameter (Fig. 6.4) or trunk girth growth (Fig 6.5) were concerned. There were periods of rapid growth (spring and summer months) and slower growth (winter months), including the control trees, which received water throughout the winter (with the exception of height growth, Fig. 6.3). Therefore it was not only drought stress that forced the trees into dormancy during the winter, but cool temperatures as well (Fig. 6.1). It appeared as if the reported necessity for drought stress to force growth check (for flowering) (Ohler, 1979) was not entirely applicable to Maputaland conditions, where it appears that temperatures cool down sufficiently in winter to perform this function.

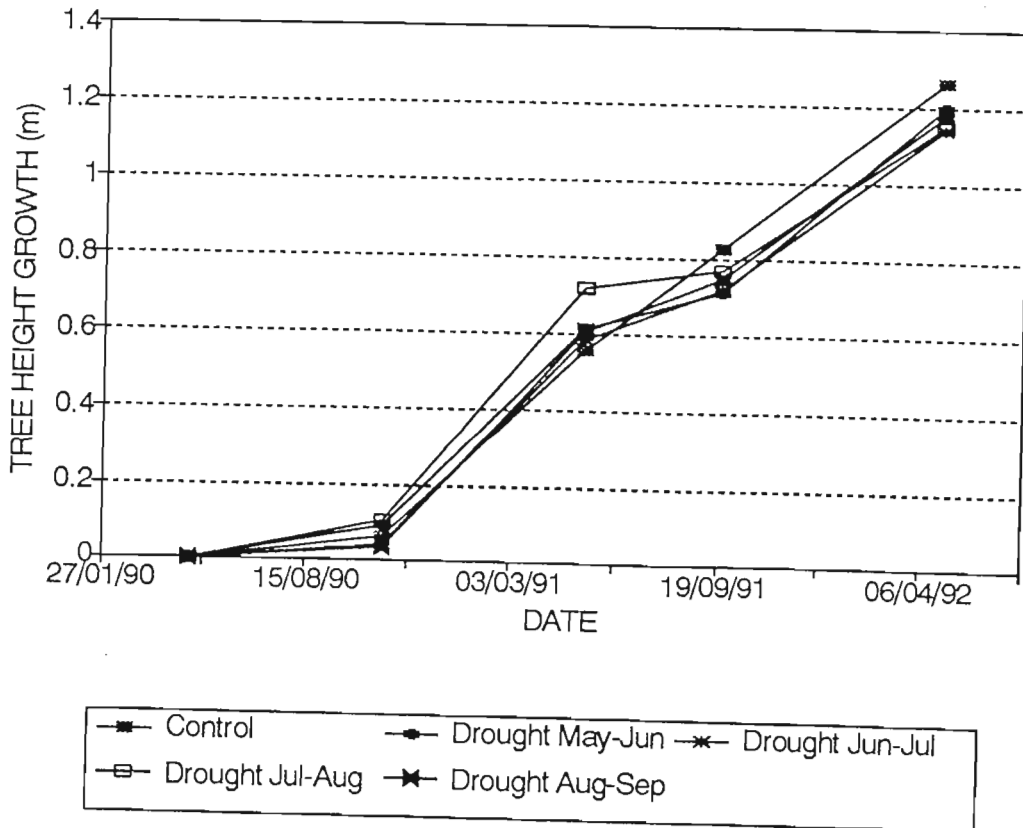


Fig. 6.3. Growth in height over the duration of the trial (1 May 1990 to 28-4-92) as affected by different timing of a 2 month drought stress period.

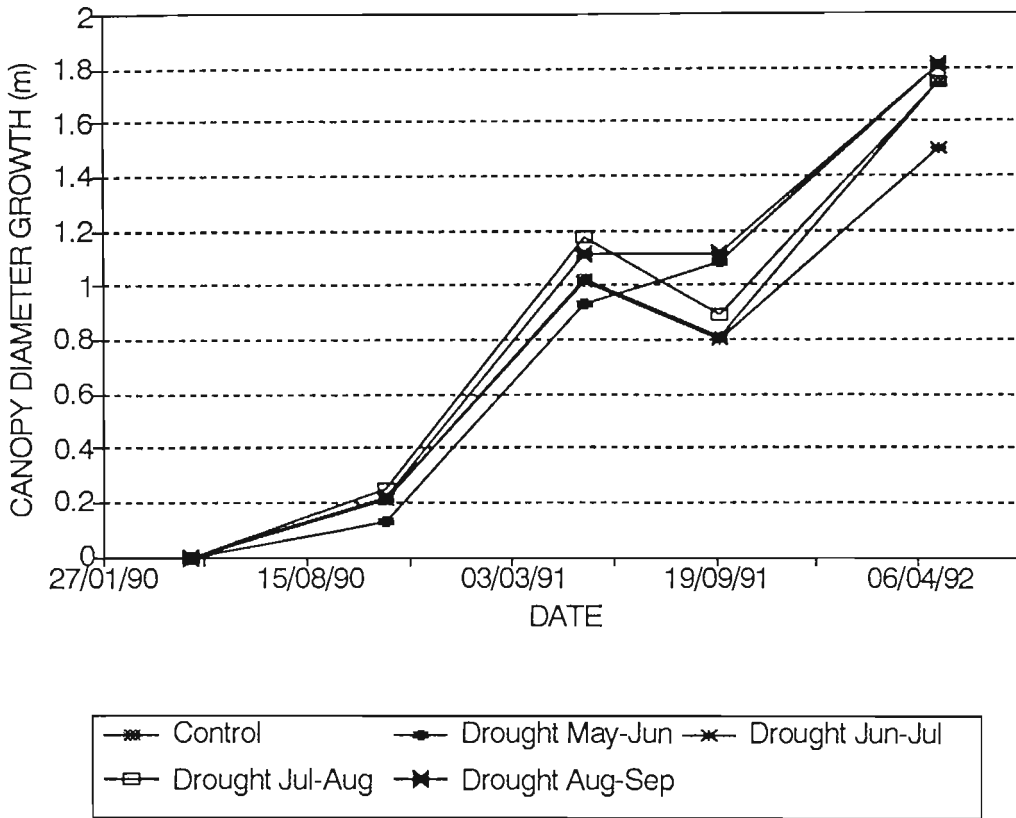


Fig. 6.4. Growth in canopy diameter over the duration of the trial (1 May 1990 to 28-4-92) as affected by different timing of a 2 month drought stress period.

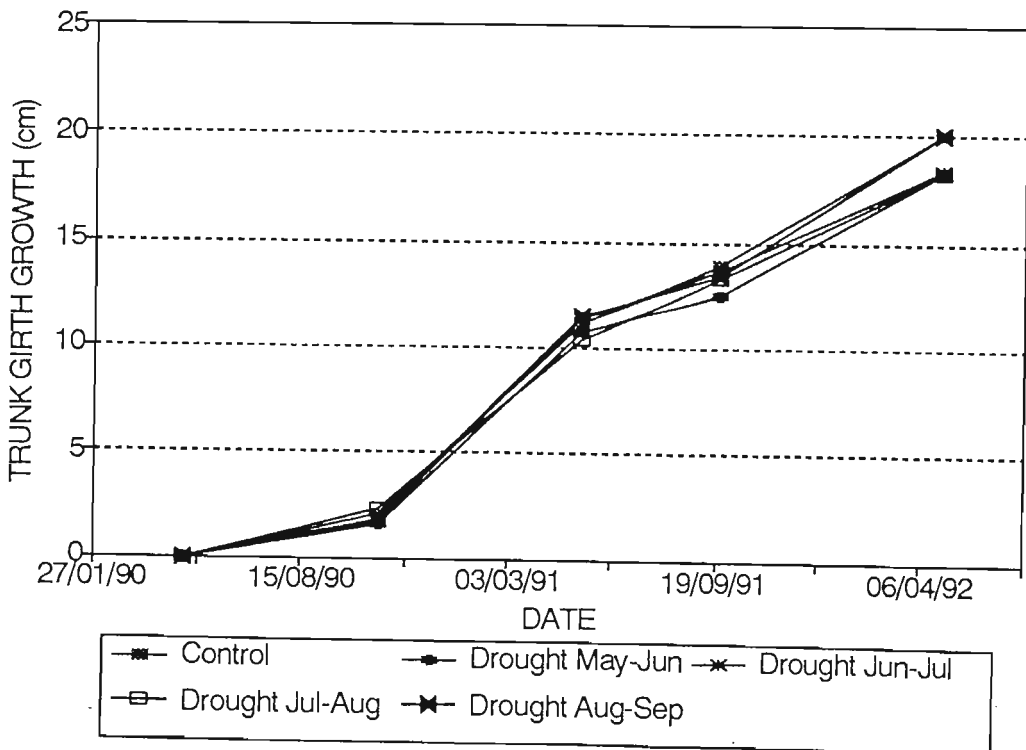


Fig. 6.5. Growth in trunk girth over the duration of the trial (1 May 1990 to 28-4-92) as affected by different timing of a 2 month drought stress period.

There were two shoot growth flushes (Fig. 6.6), one from August to October 1991, peaking in September, and the other from February to April 1992. The September flush is known as the generative flush as it is nearly always followed (or accompanied) by panicle development and flowering. The post-harvest flush in April is, in all likelihood, necessary for flowering of the following season. Rao & Hassan (1957) reported that, unlike mango, the cashew produces flowers on the current season's flushes after the growth flush at the end of the rainy season. However, from data taken in Maputaland, even though flower panicles emerge from the generative flush, floral induction usually takes place after about 6 weeks of stress, which logically is on the hardened wood of the post-harvest flush prior to the generative flush emerging.

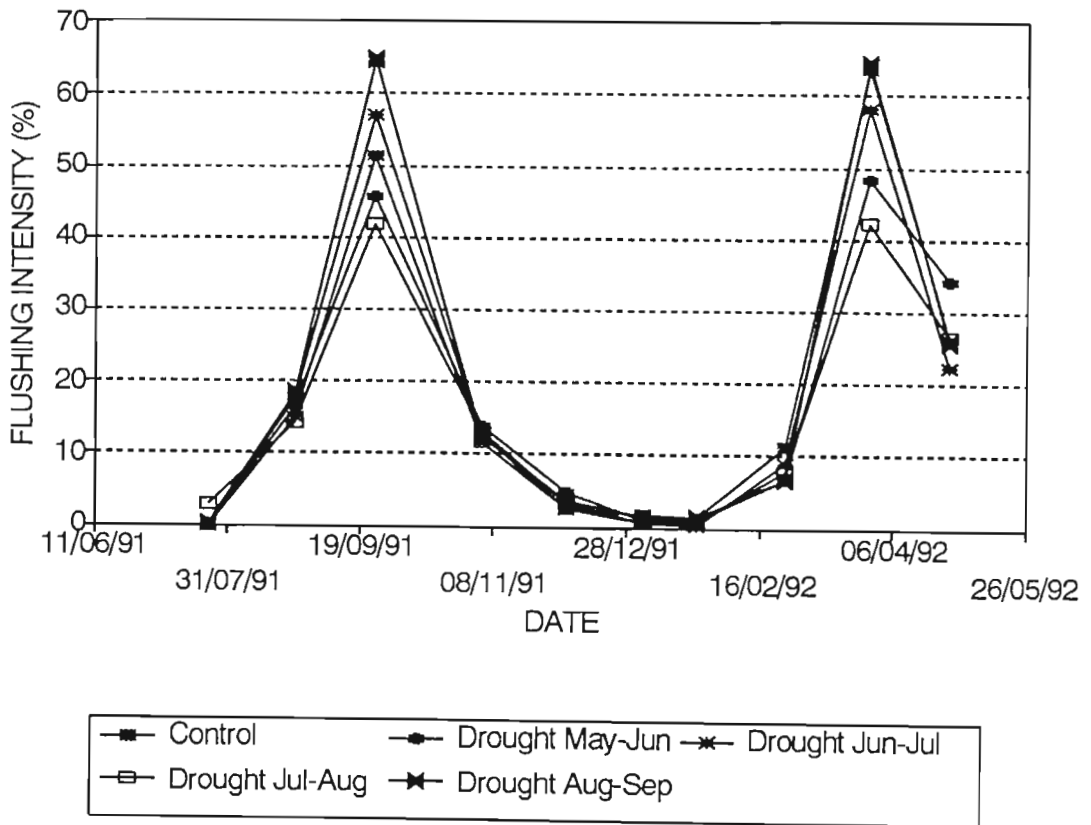


Fig. 6.6. Growth flushes of cashew trees at Makatini Research Station, over the 1991/92 season, as affected by different timing of a 2 month drought stress period.

6.3.2.2 Reproductive Growth

Panicles with unopened flower buds started emerging in mid-July 1991 and more or less ceased in late February 1992 (Fig. 6.7). Typical of cashew the flower bud intensity at any particular time hardly exceeded 15 % of the canopy surface area, but the low ratings were complemented by long flowering

duration. There were two periods where significant differences ($P \leq 0.05$) were found between the treatments regarding unopened flower bud intensity, viz. 24-9-91 and 25-2-92; otherwise there were no significant differences. By 24-9-91, the trees receiving drought during July and August had produced significantly fewer flower buds than the rest of the treatments. Flower bud production for this treatment, as well as the May-June drought treatment peaked around 12-12-91, about 2.5 months later than the other treatments (including controls) which peaked around 24-9-91. The trees experiencing drought during August-September had the highest mean flower bud intensity (22.8% in late September). This treatment had the driest period (Fig. 6.1B) of all the treatments, the rain which fell during May having dried by this stage, and the atmospheric demand for water (A pan evaporation) was becoming greater, and this possibly caused the relatively high flower bud production.

Flowering was monitored over both seasons. Due to high variation, the flowering data were transformed ($x_{Transformed} = \sqrt{x+0.5}$) which brought down the CV%, but data were detransformed for presentation. During the 1990/91 season flowering started in early October 1990 and ended in late April 1991 (Fig. 6.8A), a period spanning almost 7 months. Trees which experienced drought during August-September had significantly higher ($P \leq 0.05$) mean flower ratings (10.50% flowering) than the controls (3.44% flowering) (Fig. 6.8A). Apart from that single date there was no significant difference between treatments during 1990/91. There were two distinct peaks in flowering for all treatments during that season, one at the end of October to the beginning of November 1990, the other from mid-January to mid-February 1991. This phenomenon of more than one flowering peak has been noticed in Maputaland before this study (Cunliffe¹, unpubl. farm records., 1991), and is attributed to fungal blossom disease attack; when fungal diseases are at a peak, the flowering reaches a trough, and *vice versa*. The minima in flowering usually accompany, or closely follow, periods of high rainfall although this is not always the case. The phenomenon appears to be common in areas which experience rain during the flowering and fruiting season.

During the following season, flowering started mid-September 1991 and lasted until mid-April 1992 (7 months). There were no significant differences in flowering, but once again the trees experiencing drought during August and September had the highest peak flowering. Shifting the drought stress period had no effect on the timing of flowering, indicating the over-riding effect of cold weather and warming spring temperature in determining the onset of flowering in Maputaland.

A closer look at the climatic data (Fig. 6.1) shows that flower buds started emerging when temperatures started warming in late winter going into spring, and the beginning of flowering coincided with the period when mean monthly temperatures exceeded 23 to 25°C, and ceased in most trees when mean monthly

¹The Manager, Mosi Estate, Private Bag 330, Kwangwanase, Ingwavuma District, KwaZulu.

temperatures dropped below these levels. When considering that cashew flowering is considered to be daylength-neutral (Ohler, 1979), it is speculated that, in areas which receive extended annual cool periods (mean temperatures $< 20^{\circ}\text{C}$ for longer than 4 months), the overriding factor in flower initiation is temperature, rather than drought stress. The control treatment, which received no drought stress, flowered at the same time and intensity as the treatments which received drought stress, and this supports this argument. A more detailed study on this aspect will have to be made in order to prove this. This confirms the limited observations made previously in Maputaland which showed that flowering started when average temperatures exceeded 24°C (Staples, undated).

Menzel & Simpson (1992) showed for litchi (*Litchi chinensis* - an evergreen subtropical tree) in subtropical coastal Australia, temperature was the overriding factor over water stress in litchi flowering performance, even though it was popularly believed that drought stress was necessary for flower induction. Leaf water stress induced flowering only after cool temperatures had been experienced. Water stress applied before a period of low temperatures served to extend the dormant period, and thus increase percentage of branches flowering.

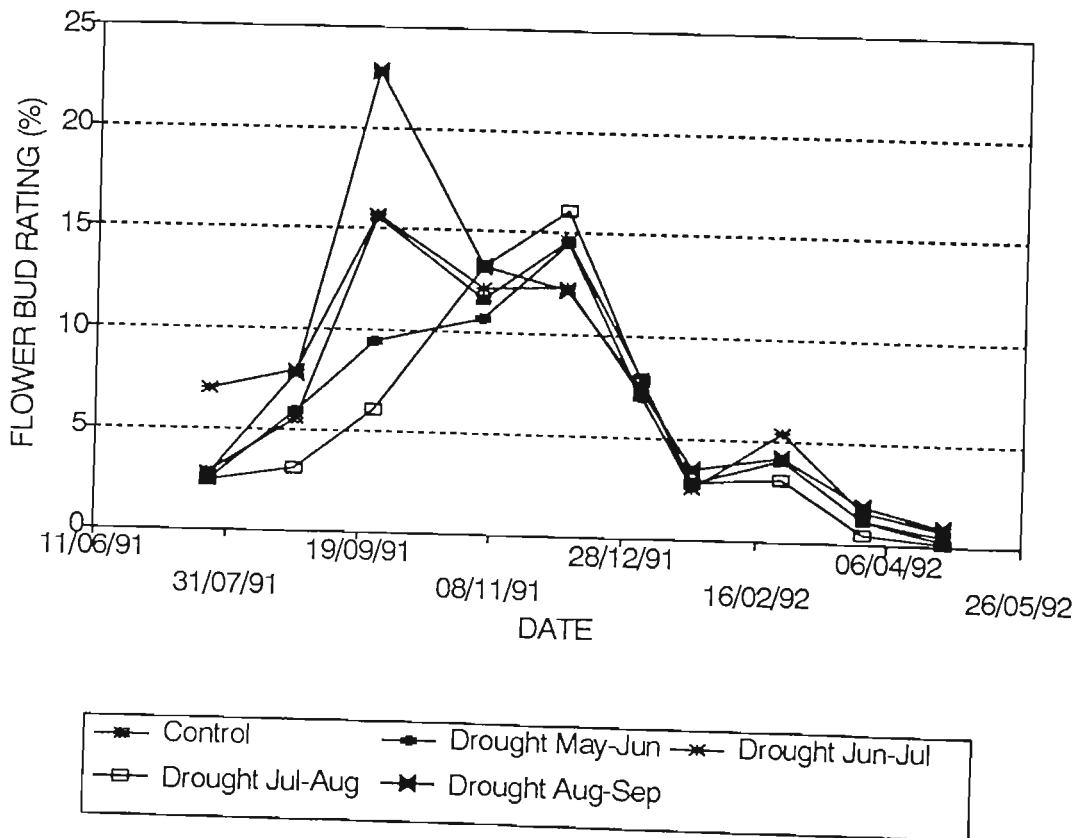


Fig. 6.7. Unopened flower bud ratings of cashew trees at Makatini Research Station, over the the 1991/92 season, as affected by different timing of a 2 month drought stress period.

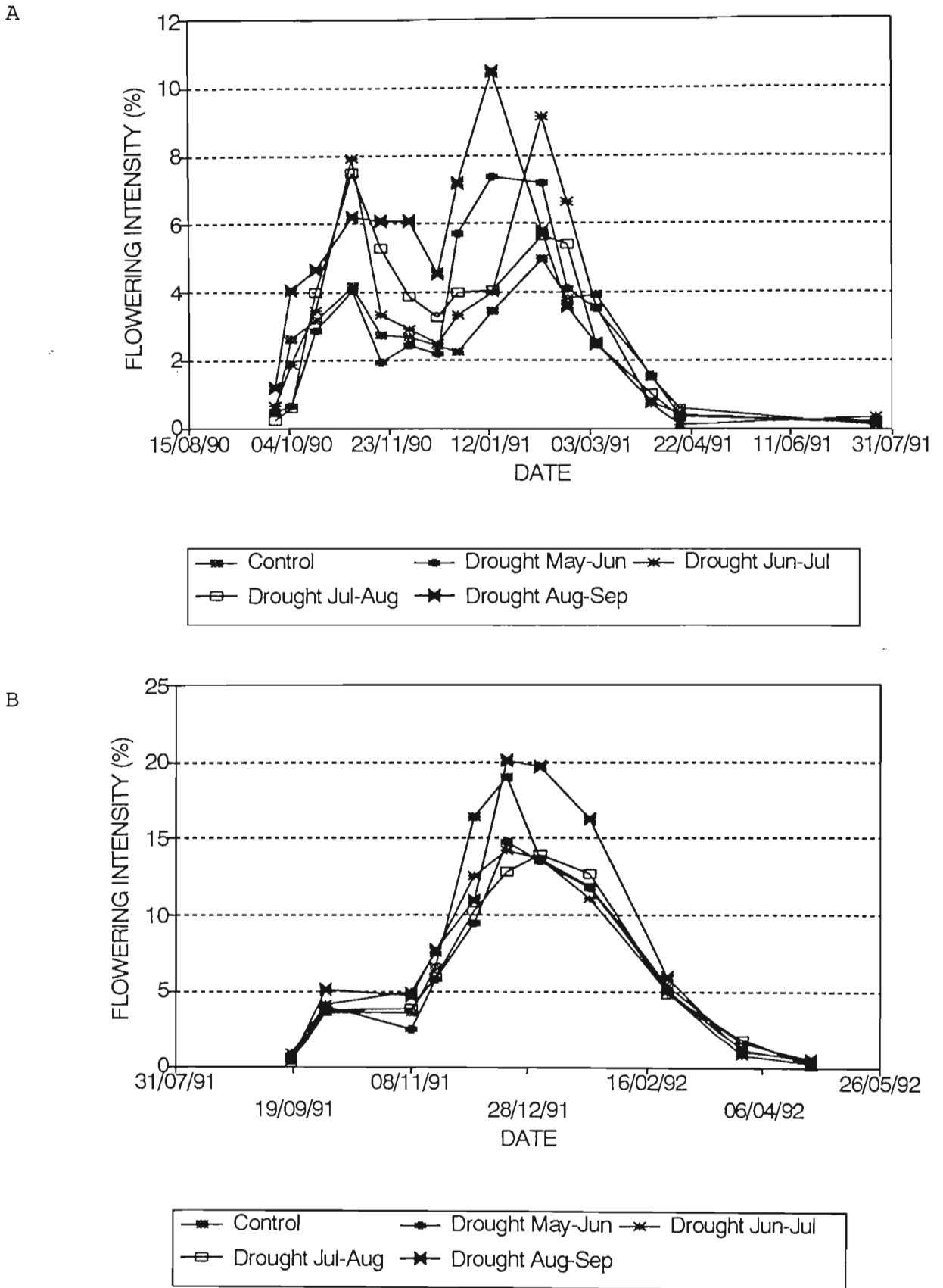


Fig. 6.8. Flower ratings of cashew trees at Makatini Research Station, over the 1991/92 season, as affected by different timing of a 2 month drought stress period during: **A** 1990/91, and **B** 1991/92.

6.3.2.3 Yields

During the 1990/91 season the yields were very low. However, there were significant differences between the treatments (Fig. 6.9). The trees receiving drought during June-July (540 g tree^{-1}), and August-September (572 g tree^{-1}) had significantly higher ($P \leq 0.05$) yields than the May-June (170 g tree^{-1}) drought treatment. The yields from the July-August (243 g tree^{-1}) and control trees (293 g tree^{-1}) were not significantly different from the former three treatments.

Total yields were much higher during the 1991/92 season, and looked quite promising for four-year old trees, and a possible cashew industry in Maputaland. Mean total yields followed a similar trend to the previous season, June-July drought ($3.83 \text{ kg tree}^{-1}$) producing the second highest yield. The August-September treatment outyielded the rest of the treatments, although the only significant ($P \leq 0.05$) difference was between the means of this treatment and July-August drought stress ($2.407 \text{ kg tree}^{-1}$).

Yield distribution (Fig. 6.10) was determined during the 1991/92 season. The harvesting period started in January and ended in April, with a peak harvesting period during February 1992. There were no significant differences between treatments at any stage during this season. The relatively good total yields for the August-September drought treatment (Fig. 6.9) resulted from consistent relatively high yields throughout the harvest period. At the beginning of the project it was thought that a shorter, more intense flowering and fruiting period would be desirable for high yields, and easier management (spray programme). However good yields were attained, even over this extended flowering and fruiting period. Management will still be easier and cheaper with a shorter flowering and harvesting period than at present.

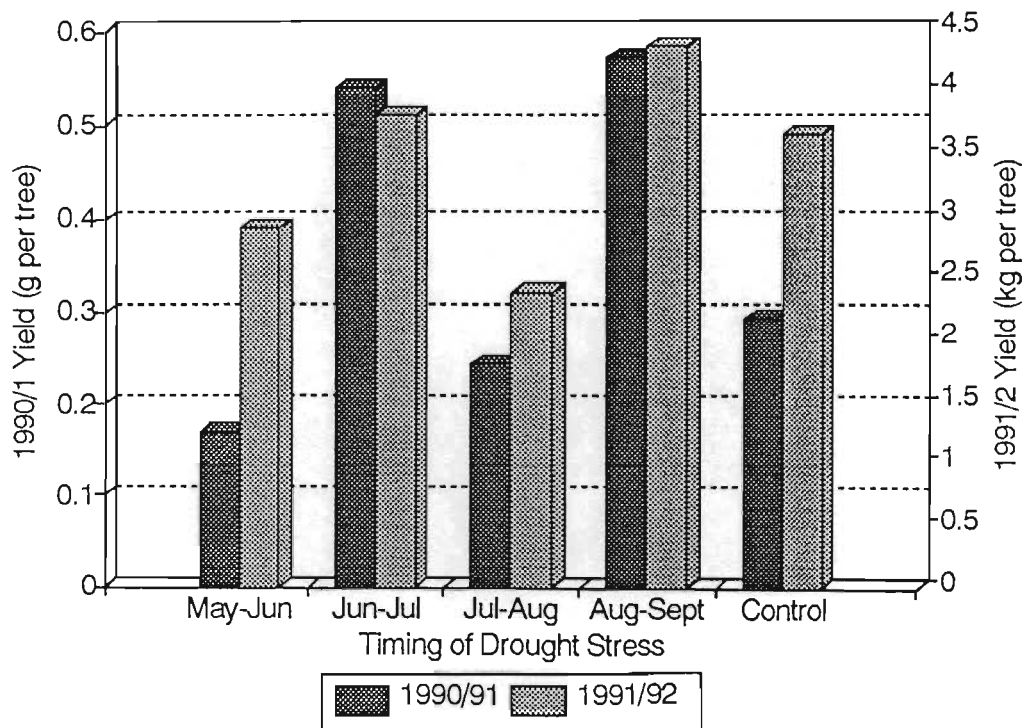


Fig. 6.9. Total yields of four-year old cashew trees at Makatini Research Station, as affected by timing of a 2 month drought stress period over two seasons.

Putting the flower bud production, flowering and yields into perspective, the relatively high flower bud production led to more intense flowering and higher mean total yields. Management should therefore aim at increasing flower bud or panicle production, by cold or drought stress, or preferably both, and try to maximise fruit set and retention by introducing bee hives, and supplementary irrigation during the flowering to harvest period.

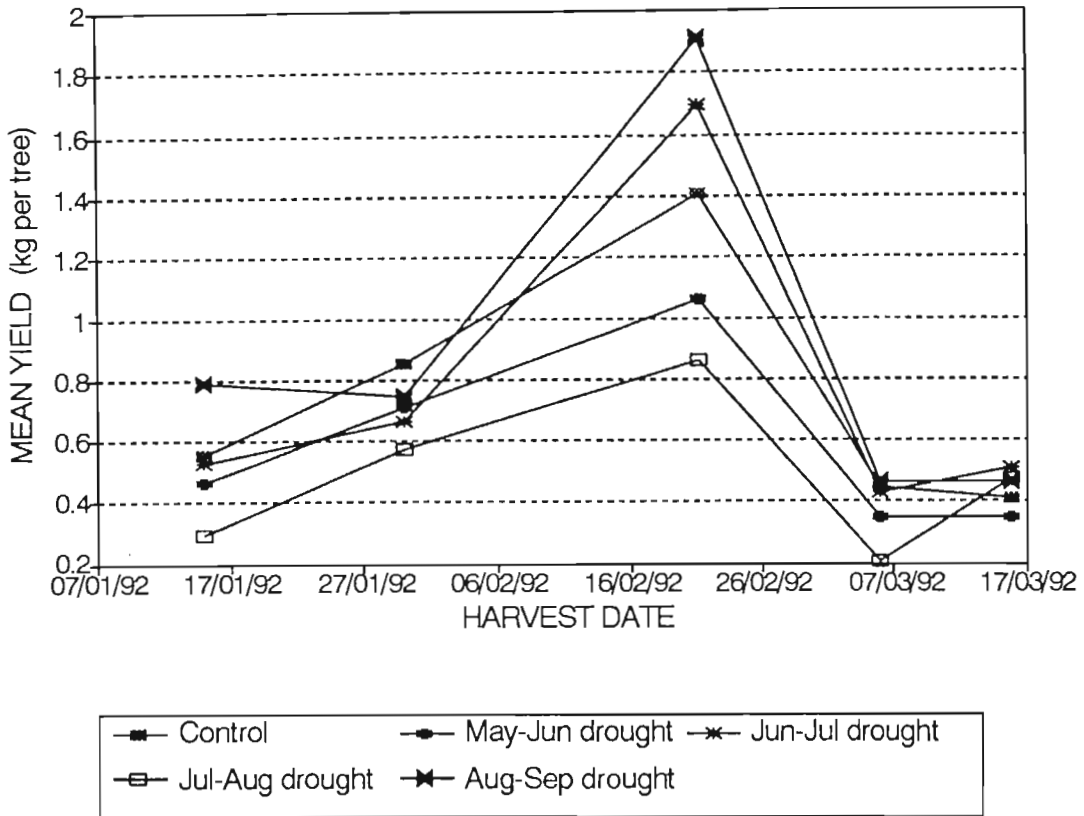


Fig. 6.10. Yield distribution of four-year old cashew trees at Makatini Research Station, as affected by timing of a 2 month drought stress period during 1991/92.

6.3.2.4 Leaf Ammonia and Trunk Starch Content

Leaf ammonia concentration is proportional to stress experienced by many higher plants (Rabe, 1990). Therefore leaves were sampled at three different times during and after the drought stress period and analysed to determine whether the cashew trees in this trial were experiencing any stress. Before the drought stress period, on 12-3-91, the leaf $\text{NH}_3/\text{NH}_4^+$ was fairly consistent (51.1 to 66.5 $\mu\text{g g}^{-1}$ DM) for all the drought stress treatments (Fig.6.11), indicating adequate growing conditions. By 14/5/91, only two weeks into first drought stress treatment, the leaf $\text{NH}_3/\text{NH}_4^+$ levels of all treatments had increased by 55.9% to a grand mean 92.1 $\mu\text{g g}^{-1}$ DM. Since the control leaf $\text{NH}_3/\text{NH}_4^+$ levels also increased, there must have been some factor, other than drought stress, leading to stressful conditions and increased

ammonia levels. This was the time when average temperatures went below 20°C (Fig. 6.1), and it is most likely that these decreasing temperatures were stressful to cashew, not sufficiently for visible stress symptoms but enough to affect tree physiology, and to increase leaf $\text{NH}_3/\text{NH}_4^+$. This is further evidence that cool temperatures may play a greater role in flowering than was originally thought.

By 25-9-91, the leaf $\text{NH}_3/\text{NH}_4^+$ decreased to similar levels to March 1991 (Fig. 6.11) (grand mean = 65.4 $\mu\text{g g}^{-1}$ DM). Another look at the temperature data (Fig. 6.1B) shows that by September 1991 the average temperature had increased to above 20°C, and more normal growing conditions had returned. This date also coincided with a period of peak flushing, which probably utilised the excess nitrogen in the leaves for growth. The differences between treatments were not significant.

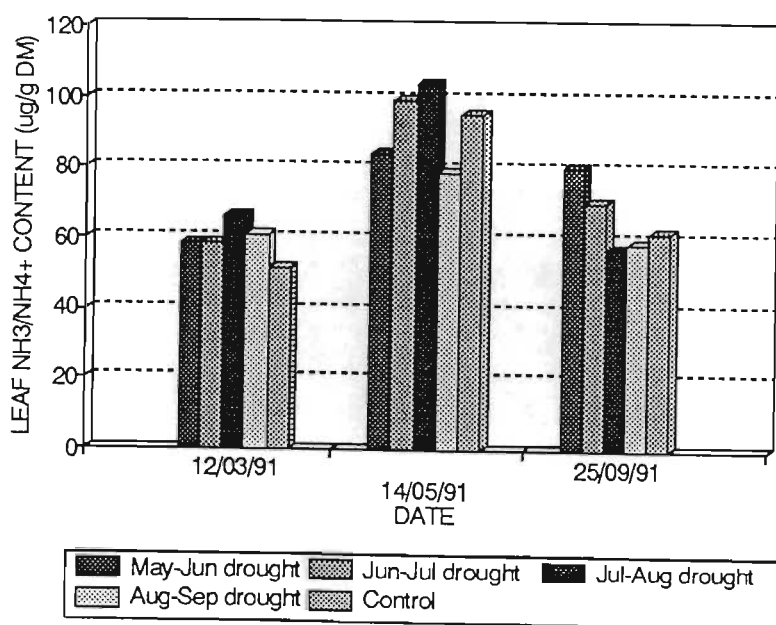


Fig. 6.11. Leaf $\text{NH}_3/\text{NH}_4^+$ content the youngest, fully expanded, hardened leaf, of cashew trees at Makatini Research Station, as affected by timing of 2 month drought stress periods during 1991/92.

Starch content (Fig. 6.12) of the tree trunks was only determined once, after all stress treatments had been completed, to see whether the treatments had any effect on stored starch in the trunk. Mean starch levels ranged from 6.4 g 100 g⁻¹ DM in control trees, to 9.2 g 100 g⁻¹ DM in trees receiving May-

Jun drought stress. However, there was no significant difference between treatments. It should be kept in mind that this was a period of active growth which was possibly using stored reserves, and the reserves were probably higher during the dormant phase in June and July. More ideally, a starch cycle should have been determined, and detailed photosynthetic studies carried out, in order to get a fuller picture of the tree physiology, but the distance from the University did not allow this.

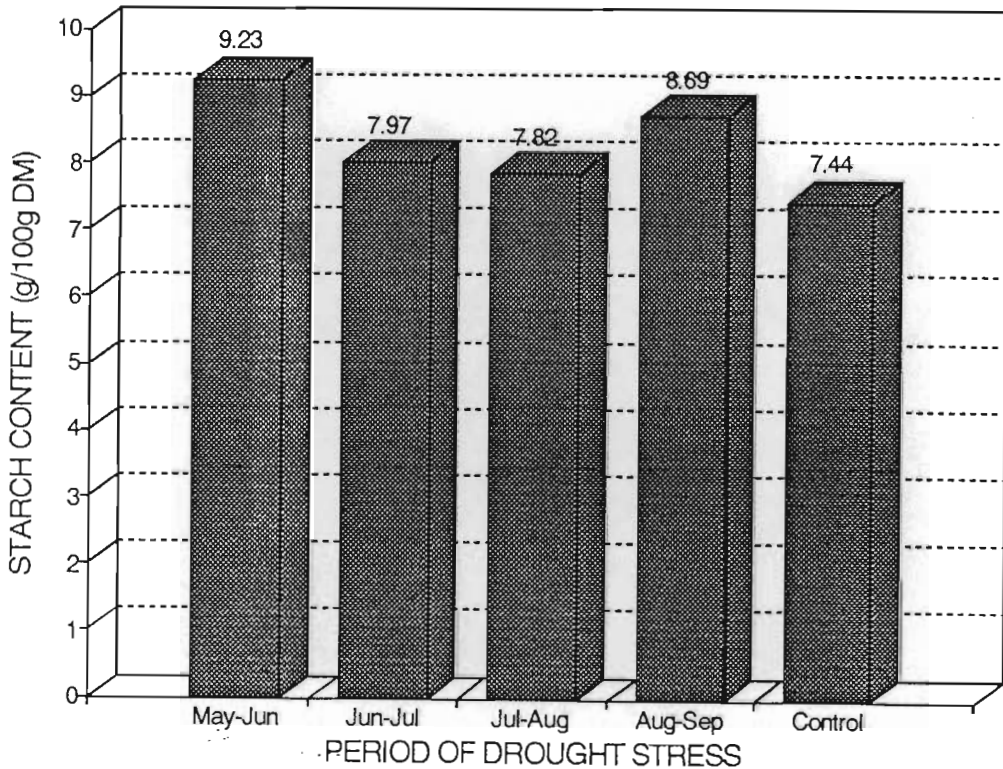


Fig. 6.12. Trunk starch content of cashew trees at Makatini Research Station, as affected by timing of 2 month drought stress periods during 1991/92.

6.3.3 Girdling Observational Trial

As previously mentioned, the observations made in this subtrial lack statistical analysis because of a lack of experimental design, as this was done using the border rows of the drought stress experiment. However it does give an idea of how girdling affected cashew tree growth, flowering and yield, as well as some physiological parameters.

6.3.3.1 Vegetative Growth

Vegetative flush ratings (Fig. 6.13A; B) show few effects of girdling on vegetative flushing. Girdling in March had no effect on flushing when compared to the control trees (Fig.6.13A), most probably because the March girdles had callused over. Girdling in May (Fig. 6.13B) appeared to suppress early

spring (August) flushing slightly, compared to controls. In September, a knife-cut cincture (1 mm girdle), and an 8 to 10 mm wide girdle in May, decreased flushing considerably compared to control trees. There appears to have been too little time for the May girdles to have callused over by then. The narrowest girdle callused over in approximately 2 months, the 5 mm girdle in approximately 4 to 5 months, and the 10 mm girdle took more than 6 months, and in one case a tree died from the stress. A 10 mm girdle is therefore considered too wide for cashew and should be avoided. These observations were also only done for one season, and therefore the effects of repeated annual girdling cannot be commented on.

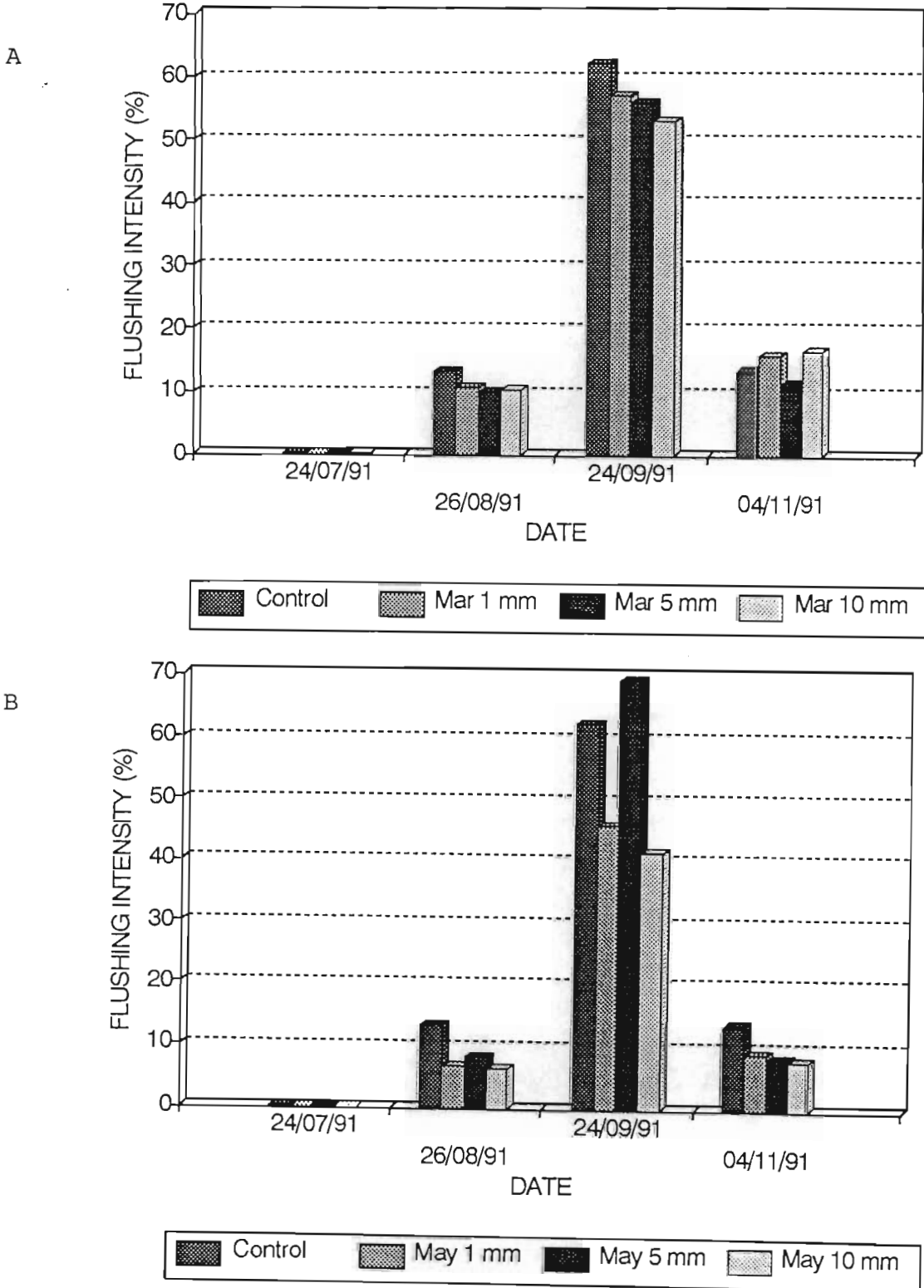


Fig. 6.13. Flushing of cashew trees at Makatini Research Station, as affected by three girdling widths applied in A. March 1991, and B. May 1991.

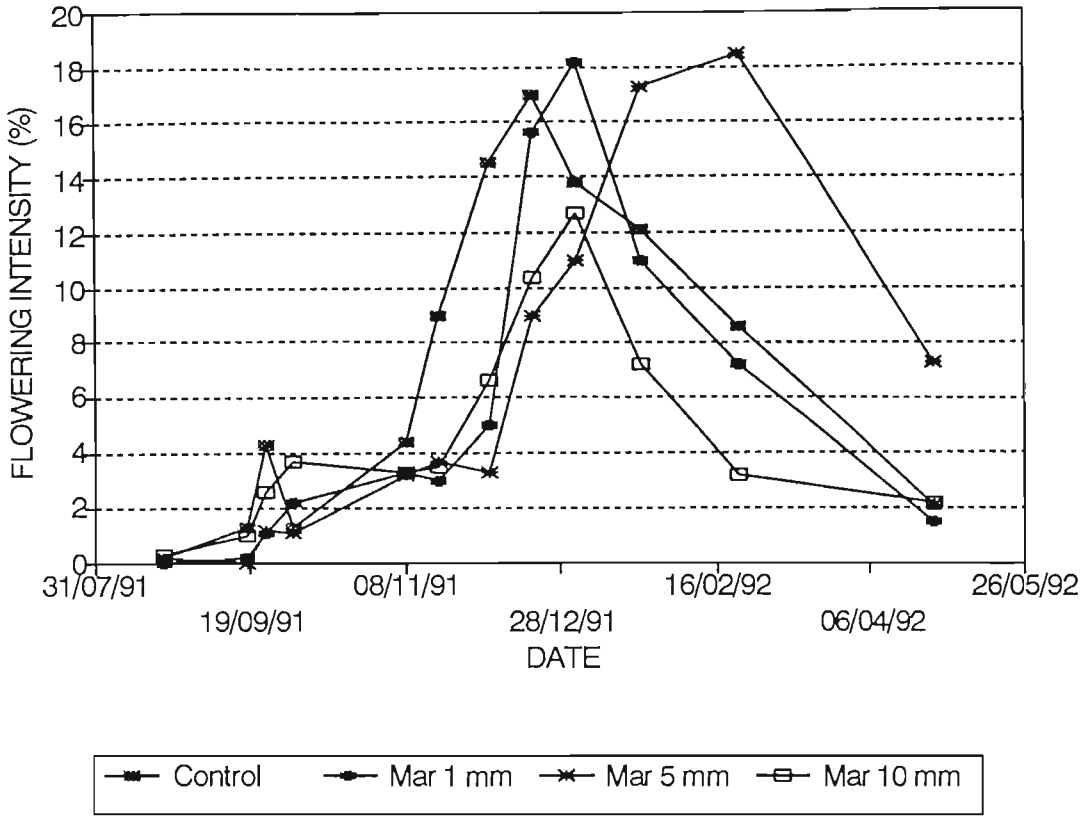
6.3.3.2 Reproductive Growth

Girdling affected mainly the timing, and to a lesser extent, the intensity of cashew flowering (Fig. 6.14). The narrowest girdle (1 mm), administered in March or May, did not affect flowering in any major way, and was quite similar to control trees, and this may be attributed to the quick callusing over and healing of this narrow wound. Although flowering of all treatments started at the same time (in September 1991), a 5 mm wide girdle resulted in considerably later flowering (February 1992) than controls which peaked in early December 1991, and this was consistent for both March and May girdles. Flowering intensity of both March and May 10 mm girdled trees was lower than controls, possibly due to the stress still imposed on the tree, and disturbed physiology, by having an unhealed girdle for an extended period.

The primary effects of girdling are reported to be due to the effects the accumulation of substances above the girdle. These substances are thought to be either carbohydrates, which serve as an energy source (Wallerstein, Goren & Monselise, 1978), or changes in hormonal balance (Wallerstein, Goren & Monselise, 1973). The arguments for both explanations are not entirely infallible and there are some uncertainty on the mode of action, as pointed out by Cohen (1981). Cohen (1981) proposed a much broader and less specific approach to the mode of action of girdling. His assumptions were based on the magnitude of effects, which is dependent on the number of leaves, and the time taken for girdling wounds to heal. He pointed out that all observations show that girdling affects mainly the rate of existing processes, but does not alter them in any other way. The damaging effects of girdling (root starvation and hindrance of xylem movement) are usually noticed long after the wounds have healed.

In the light of this reasoning, the build-up of flowering inhibitors, most likely gibberellins (Wallerstein, *et al.*, 1973) above the 10 mm girdles of cashew trees may have resulted in a decrease in flowering intensity, because of the long duration of unhealed wound. For the trees with a 5 mm girdle the period taken for healing was much shorter, and therefore the flower inhibitive effect may only have been present for a few months, and therefore served only to delay flowering and not decrease its intensity. The time taken for the 1 mm girdle to heal was short enough for flowering to continue as normal.

A



B

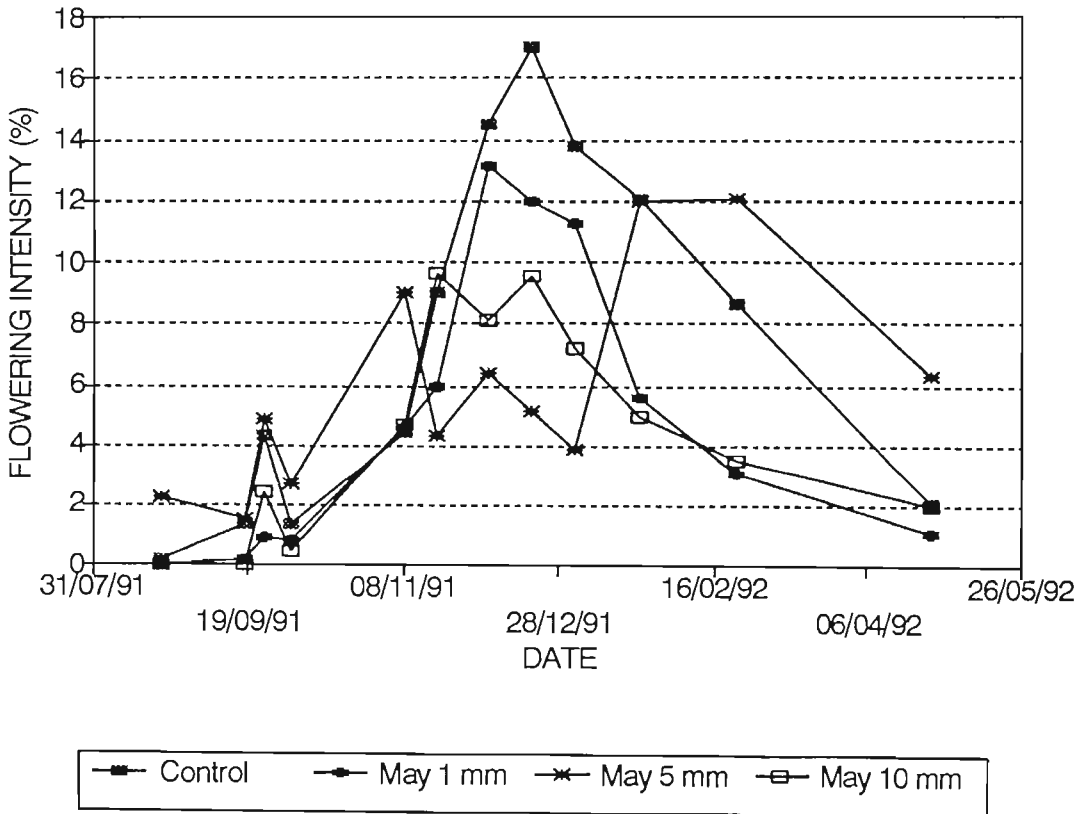


Fig. 6.14. Flowering of cashew trees at Makatini Research Station, as affected by three girdling widths applied in A. March 1991, and B. May 1991.

6.3.3.3 Yields

Contrary to expectations, total yields were depressed markedly by girdling in March and May (Fig.6.15). Control trees yielded exceptionally well (mean of 6.8 kg tree) for four-year old cashew trees. All the girdled treatments produced approximately half the yield of the control. Peak harvest was in mid-February for all treatments. Although healthy looking trees were sought out for this study, the trees may not have been in optimum condition (marginal climate, fertilisation, etc.), and as Cohen (1981) reported, girdling of trees which are not in top condition for any reason may cause severe injury, even by the mildest girdling treatments. This may have caused the relatively low yields experienced by girdled trees. These results were convincing and showed that girdling, under the conditions experienced during the trial, could not be recommended.

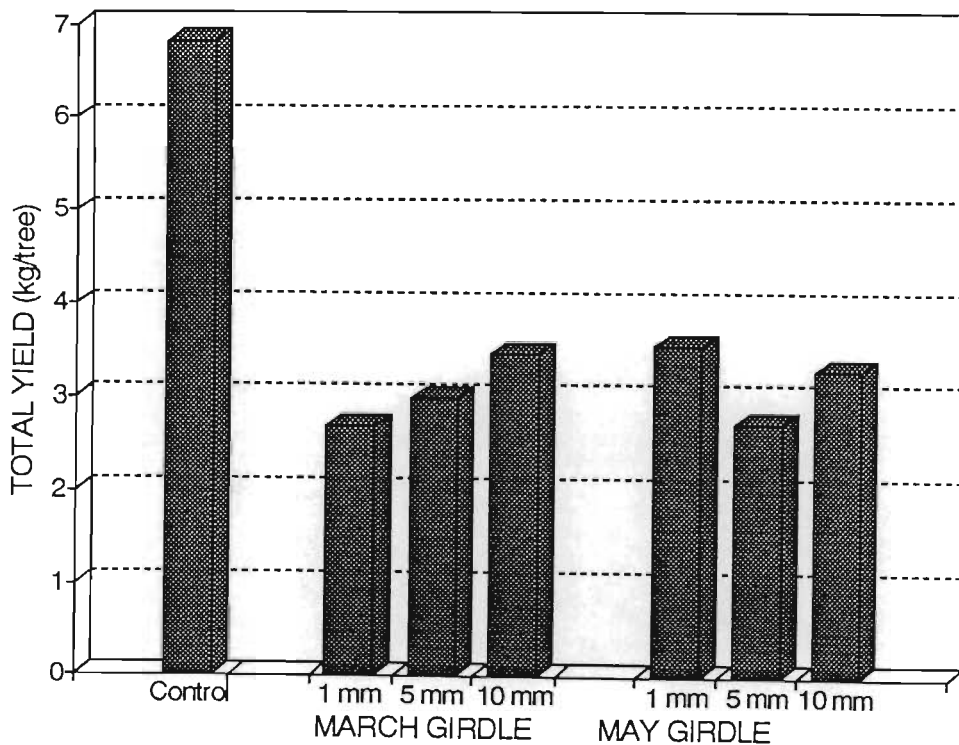
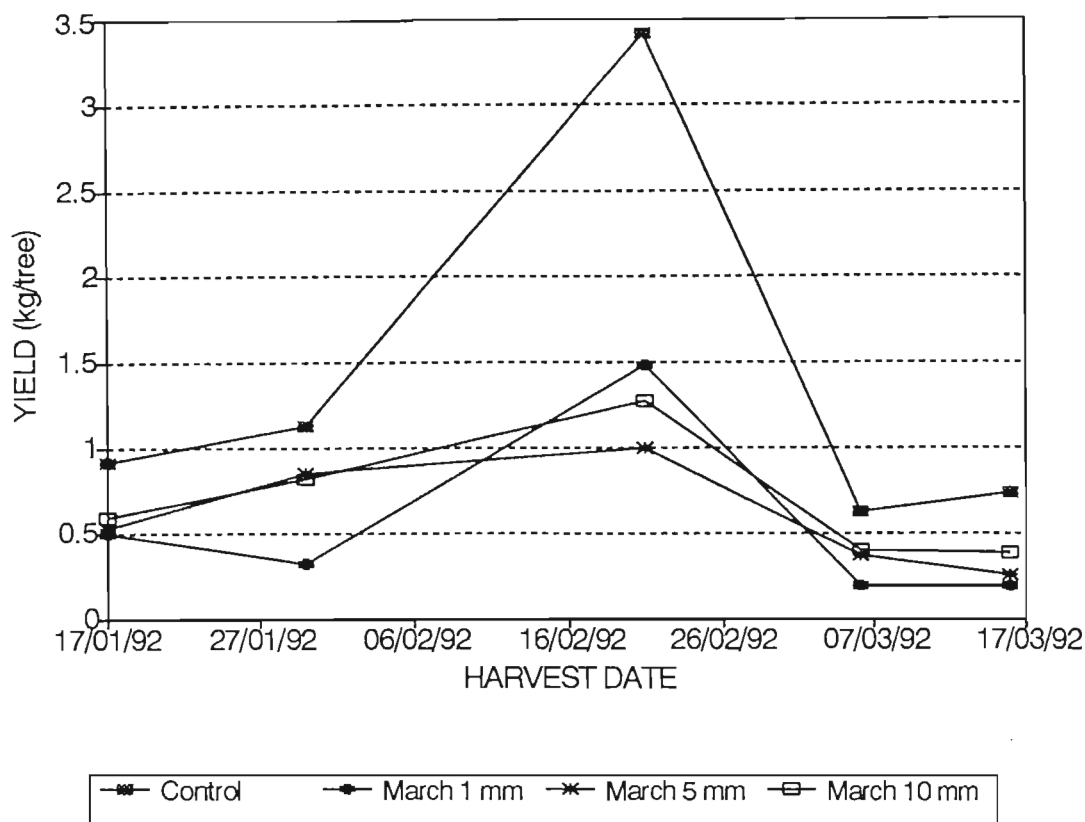


Fig. 6.15. Total yields of cashew trees at Makatini Research Station, as affected by three girdling widths applied in March and May 1991.

(A)



(B)

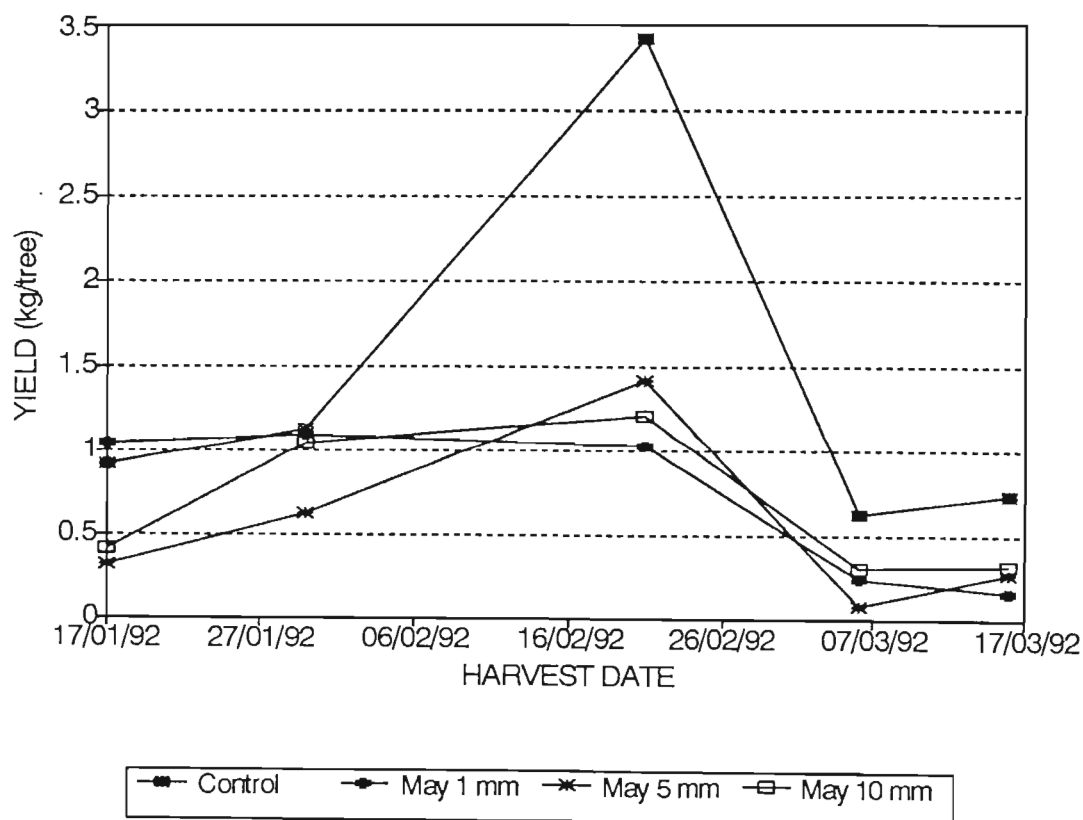


Fig. 6.16. Yield distribution of cashew trees at Makatini Research Station, as affected by three girdling widths applied in March (A), and May (B) 1991.

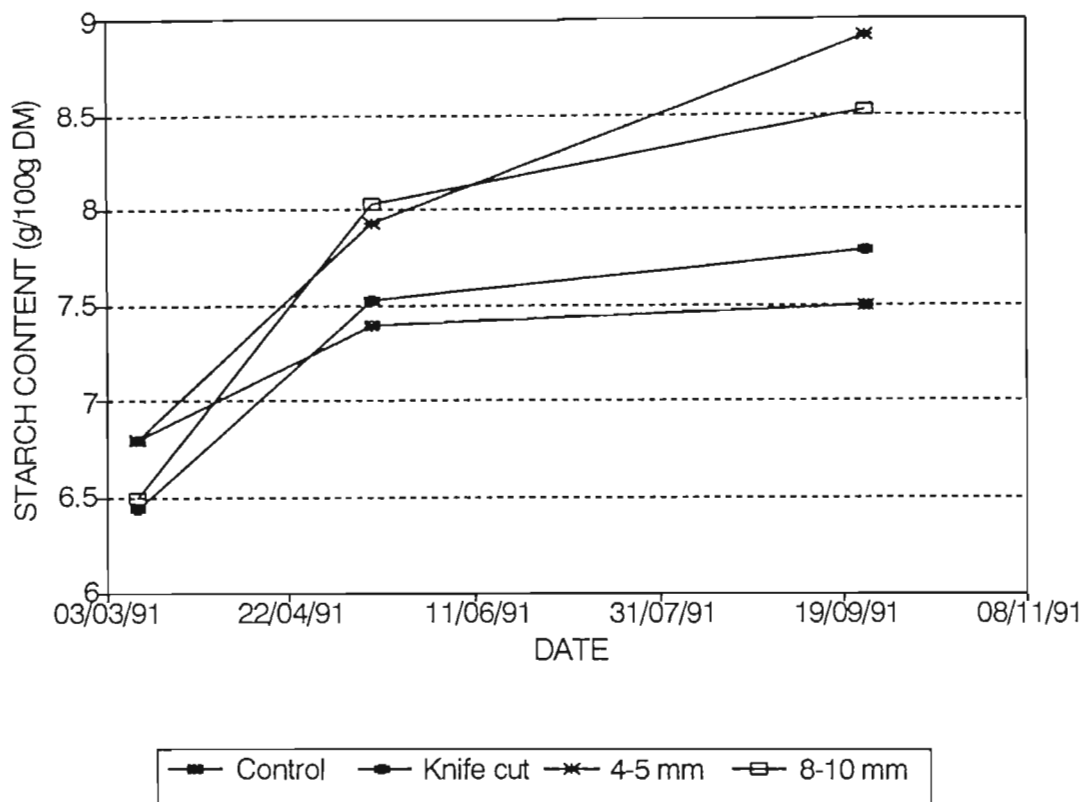
6.3.3.4 Trunk Starch Content

Trunk starch content above the girdle (Fig. 6.17) was determined at the time of March girdling (12-3-91), May girdling (14-5-91), and after growth activity had started in spring (25-9-91), to monitor a possible carbohydrate build-up. Levels at the start of the trial varied from 6.4 to 6.8 g 100g⁻¹ DM. Starch levels of control trees increased during the dormant winter period, and were at the same level in September during peak flushing. It is assumed that starch levels of the control trees increased more into July and then decreased after flushing started. For trees girdled in March (Fig. 6.17A), there was sharp increase in starch content above the girdle during winter, and less of an increase by spring, when growth had restarted. The narrowest March girdle, after an initial rapid increase in starch content, more or less followed the curve of the control trees, whereas the wider girdles resulted in further increases in September 1991. Presumably, these patterns were linked to the time taken for the girdle wounds to heal. Girdling in May (Fig. 6.17B) resulted in similar sharp increases (for all girdle treatments) after girdling, compared to the control trees.

On 25-9-91 starch content on both sides of the girdle was determined (Fig 6.18) to see if differences had resulted from the girdle. There was a small difference across the girdle for both the March and May 1 mm girdled trees. Wider girdled trees had bigger differences (up to 0.9 g 100g⁻¹ DM greater above March girdles, and 2.1 g 100 g⁻¹ DM above May girdles). These differences were much greater for May girdled trees than the March girdled trees. A possible explanation for this is that March-girdled trees had had more time to heal the wounds, and therefore the differences were small, compared to May-girdled trees which were still in the process of healing, particularly the wider girdles. Another possibility is that the roots had started to become active, and were using starch reserves below the girdle, which for some May-girdled trees had not fully callused over and healed, hence the lower starch levels below the girdles of the May-girdled trees.

One would expect the increases in carbohydrate above the girdle to promote flowering and yields. However, starch is a storage carbohydrate, which cannot exclusively influence these processes, but it can be important for fruit set by reducing competition between shoot, root and flower growth (Erner, 1988). The decreased flowering of trees with wide girdles may be due to a build-up of gibberellin-like substances detected by Wallerstein *et al.* (1973) in citrus, and this may also have affected yields. There is also a possibility that girdling may adversely affect the lactifers and interfere with the essential latex-mediated maintenance of leaf turgor. Whatever the cause, the results do not encourage the use of girdling as a tool to improve flowering and yields of cashew trees in Maputaland.

(A)



(B)

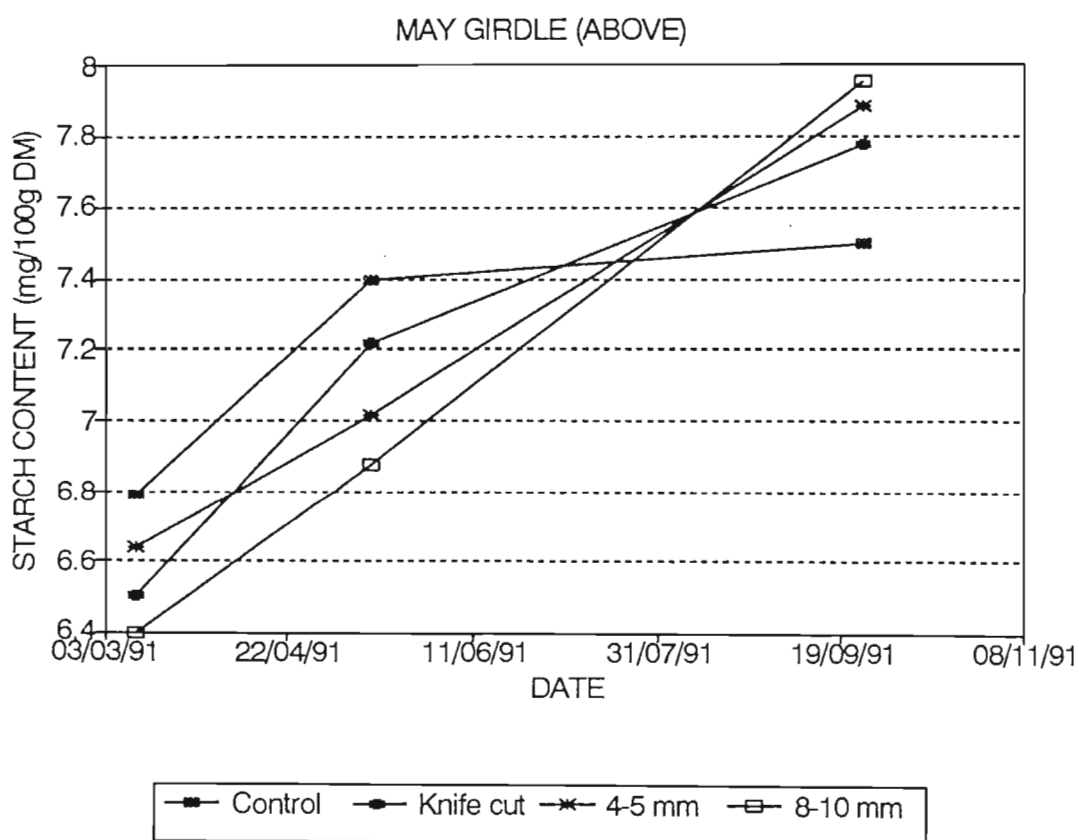


Fig. 6.17. Trunk starch levels above the girdles of cashew trees at Makatini Research Station, as affected by three girdling widths applied in March (A), and May (B) 1991.

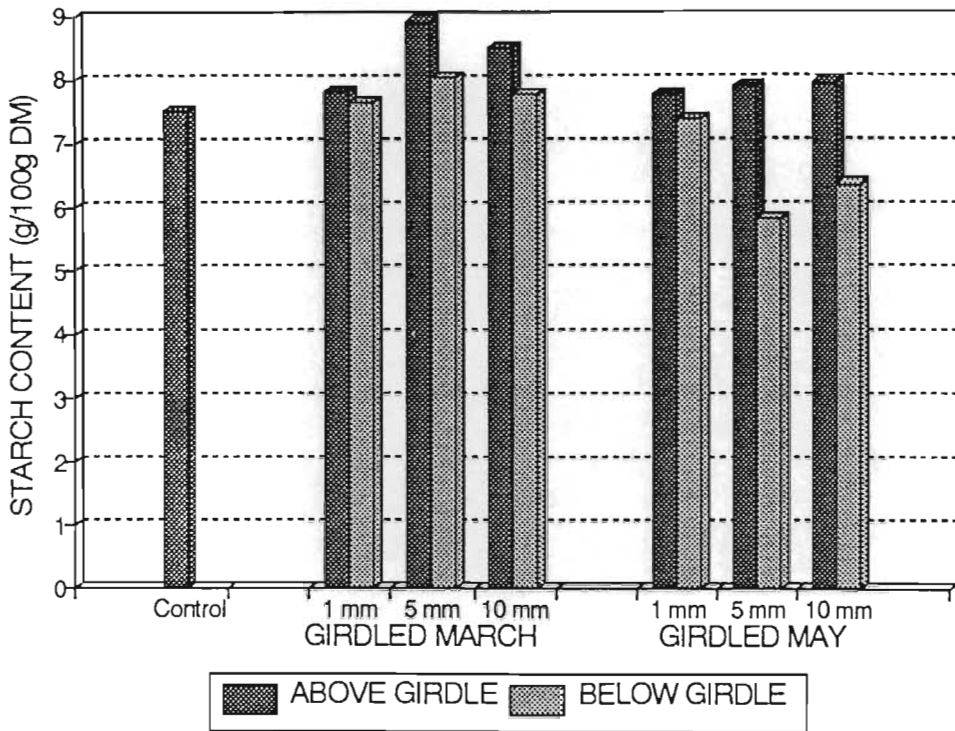


Fig. 6.18. Trunk starch levels above and below the girdles of cashew trees at Makatini Research Station, as affected by three girdling widths applied in March and May 1991.

6.4 CONCLUSIONS

It is clear that autumn and winter temperatures were sufficiently cool to force a growth check of cashew trees at Makatini Research Station, in Maputaland. It was also clear that growth, flowering and fruit production were not affected in any significant way by receiving no drought, and therefore the cool temperatures were able to induce flowering satisfactorily. Drought stress was therefore not necessary in the presence of cool temperatures ($< 20^{\circ}\text{C}$ mean monthly temperatures; 10 to 12°C mean minimum), and also probable access of roots to a high water table, for flowering in Maputaland. In the author's opinion, it is nevertheless desirable to have a drought stress period, in case warmer winters are experienced. It is possible that the drought stress treatments in this trial were not long enough and did not induce enough stress to result in higher flowering intensities; a three month (or longer) drought period may have had more convincing results in favour of drought stress. On the other hand, the weight of evidence suggests that winter cold was the over-riding dormancy-inducing factor.

The economic aspects of drought stress must be taken into consideration, and in this respect, it would be cheaper to impose a drought stress period throughout the dry winter period. The marginality of the

area for cashews means that it may not be economically viable to install a moderately sophisticated irrigation system, and in fact, may not be necessary in many places in Maputaland, because of a shallow water table (0.5 to 5 m below soil surface). There was a concern that this shallow water table in Maputaland would result in inadequate drought stress during winter if the water levels did not drop during this time, but this concern can now be put to rest. Under Maputaland conditions, it is winter cold which is mainly responsible for inducing the growth check that is a pre-requisite for flower induction. Relatively cool winters also delay the onset of the post-dormancy growth flush (which is accompanied by flowering) to much later period than, for example, in central Mozambique.

As far as the timing of drought stress is concerned, late winter drought stress (August -September) appeared to show promise by having the highest flower intensity and yield. Early winter stress (May to July) resulted in mediocre flowering and yields, and showed neither promise nor harmful effects. However, the generally erratic nature of the rainfall distribution in Maputaland, without a pronounced monsoonal dry season, plus the undoubted access of deep roots to a fluctuating water table, leave little scope for purposeful manipulation of the winter drought period.

Flowering started when the mean temperature went above 23 to 25°C, and continued until the mean temperature dropped below 23 to 25°C in autumn, and therefore the critical temperature above which flowering and fruit production occurs must lie between these temperatures. Only with more detailed studies under controlled temperature conditions, using clonal trees to reduce the variability, will we be able to determine the exact critical temperature. The concept of heat unit accumulation, probably after July, could undoubtedly be applied to predict more accurately the onset of growth in spring, and therefore the timing of flowering. It appears that considerable heat units must accumulate before growth starts.

Nut quality is an important factor when determining the economic benefits from any of the treatments, but due to a lack of processing facilities, quality of nuts was not determined. Future research will have to include quality analysis, preferably with a mini-processing plant, because hand processing is largely ineffective.

Although the girdling trial was not statistically laid out, a number of conclusions can be drawn. The widest girdle (10 mm) for both March and May decreased flowering intensity. A 5 mm girdle delayed peak flowering by up to two months. Starch levels above the girdle built up considerably but this was unable to increase yields in any way. Yields of all girdled trees were approximately 50 % those of ungirdled trees. Therefore, from these results, girdling cannot be recommended as a yield improving technique, even though flowering was influenced. Girdling of the main stem, in fact adversely affected cashew trees under the conditions of this trial, probably because excessive vigour was not a problem, and leaf abscission was increased.

Further studies required include photosynthesis (to monitor production of carbohydrates under the above conditions and treatments), temperature effects on flowering and growth under controlled conditions, girdling at different times, using trees in optimal health, and other physical tree manipulation techniques such as root pruning and different methods of canopy pruning. Girdling of individual branches, rather than the trunk, may have benefits in inducing greater flowering in excessively vigorous trees.

CHAPTER 7: ATTEMPTS AT CHEMICAL MANIPULATION OF FLOWERING AND GROWTH OF CASHEW TREES IN MAPUTALAND

7.1 INTRODUCTION

When compared to most other fruit and nut tree crops, very little research into cashew flower manipulation has been undertaken. To manipulate flowering and growth of cashew trees two strategies may be followed. The first is to use cultural means to reduce vegetative growth and try to improve flowering and fruit set. This strategy was followed at Makatini Research Station (Chapter 6). The other is to use chemical tree manipulation techniques, including the application of plant growth regulators (PGR) or inhibitors, or other chemicals which may affect growth or flowering. This strategy was applied in a field trial at Mosi Estate.

Ethylene inhibits flowering in most species, but in a few species (mango - a member of the family Anacardiaceae; bromeliads, pineapples) flower induction is promoted by this PGR (Salisbury & Ross, 1978). Ethephon concentrations used for flower manipulation in mangoes vary from 500 mg l⁻¹ (Nunez Elisea *et al.*, 1986) to 4600 mg l⁻¹ (Capote & Naveira, 1987), but in cashews concentrations of 200 mg l⁻¹ have been shown to influence sex ratios. Potassium nitrate has also been shown to be effective in mango flower induction in the tropics (Bondad & Linsangan, 1979; Mosqueda Vasques & Santos de la Rosa, 1982), and urea foliar applications have resulted in increased flowering in citrus (Lovatt *et al.*, 1988). Being a member of the Anacardiaceae, the same family as mango, it was decided to see whether the same applied to cashew.

The use of KNO₃ and urea to manipulate flowering are related to N-containing compounds and stress physiology. Any stress inhibiting the growth of a plant will result in the accumulation of ammonia (measured as the combined pool of NH₃/NH₄⁺) in its leaves (Lovatt *et al.*, 1988). Rabe (1990) wrote that since stress is usually a requirement for flowering in many commercial tree species, the intensity and timing of flowering could be controlled by exogenous application of chemicals which result in higher endogenous ammonia levels, thus "artificially" inducing stress.

Galang & Lazo (1936) found that productivity of cashew was associated with leaf area and internode length. Dasarathi (1958) noted that trees with excessive growth and long internodes bore less than those with slow or medium vegetative growth. Paclobutrazol (PP333) has been used successfully to control vegetative growth and improve flowering and yields in many temperate and subtropical fruit crops (Goldschmidt & Monselise, 1972; Quinlan, 1981; Raese & Burts, 1983; Bausher & Yelenosky, 1986; Edgerton, 1986; Looney & McKellar, 1987; Early & Martin, 1988; Harty & van Staden, 1988; Kadman *et al.*, 1988; Kulkarni, 1988; Menzel & Simpson, 1990; Rowley, 1990a,b; Köhne, 1990;

Wolstenholme *et al.*, 1990). This chemical has been shown to cause a decrease in internode length, resulting in decreased tree vigour and the promotion of flowering in bearing trees, and precocious flowering in young grafts.

In this field trial the effects of ethephon, paclobutrazol, KNO_3 and urea, at different concentrations, on the growth, yields, and particularly flowering of cashew trees in Maputaland, were investigated.

7.2 MATERIALS AND METHODS

Seventy-eight three to four-year old (second year of bearing) cashew trees at Mosi Estate, near Kwangwanase and the Mocambique border with northern Natal/KwaZulu, were made available for this trial. The trees had been used in a fertilizer trial immediately prior to this trial, and therefore all the trees from a single fertilizer treatment (2 x optimal fertilization) were selected. The trees were growing on marshy soil (Champagne form, Mposa series, Appendix IV) with a water table varying from 50 cm to 2 m below the soil surface, but this fluctuated according to the amount of rain. There was no irrigation but the trees received adequate water from rain and the shallow water table, and nutrition from organic mulch and inorganic fertilizers. The trial plan is shown in Appendix VIII.

During the first year of the project the treatments (Table 7.1) applied consisted of foliar applications to run-off of the different chemicals during winter (July) of 1990. A wetting agent, NuFilm 17^R, was used to get maximum absorption.

During the following year foliar sprays were applied on a phenological basis rather than on calendar time, because from the first year's results it appeared that July was not the ideal time for foliar application for any of these chemicals as very few trends could be picked up regarding growth, flowering or yields. Paclobutrazol was sprayed during the vegetative flush (end of March 1991) following the main harvest period. Ethephon concentrations were increased to 100, 500 and 2000 mg l⁻¹ and were repeated three times at weekly intervals at the end of the vegetative growth flush (May 1991). Urea and KNO_3 sprays were timed to coincide with the estimated time of flower induction during June/July. Bark samples were taken from the trunks of all trees in the trial at regular intervals, and starch analysis was carried out as described in 3.3.2. At the same time, leaf samples (the youngest, fully hardened leaf) were taken to determine leaf $\text{NH}_3/\text{NH}_4^+$ content as described in 3.2.3.2. Due to the expense of this technique leaf samples of each treatment were pooled, and therefore no statistical analysis could be performed.

During May 1991 the orchard was flooded after very heavy rains, and during October 1991, a hail storm damaged leaves and knocked off the major proportion of flowers. These unforeseen events adversely influenced the experiment.

A randomised blocks design using single tree plots and six replications was utilised. Statistical analysis included tests for Kurtosis and skewness of data distribution, and analysis of variance. The trees were grown from seed and as a result were extremely heterozygous. Due to data consisting of small whole numbers, and high coefficients of variation (CV %) (Steele & Torrie, 1980) the data from flowering, vegetative flushing and unopened flower bud ratings were square root transformed ($x'=\sqrt{x+0.5}$). The transformed means were detransformed before presentation.

Due to the great distance between the University of Natal and Mosi Estate (± 500 km) data collection had to be limited to the most essential. Tree growth rates (in height, canopy diameter and trunk girth), phenological ratings (vegetative flushing, unopened flowering buds and flowering) on a percentage canopy surface area, yields, and climatic parameters were recorded. A phenological model was drawn up by the author from an average of the data of all field trials.

Table 7.1. Treatments applied during 1990/91 and 1991/92 to three-year old cashew trees in a chemical spray trial at Mosi Estate.

Treatment	1990/91 (sprayed July 1990)	1991/92
	Concentration (active ingredient (a.i.))	Concentration (active ingredient (a.i.))
1. Control (no spray)	---	---
2. Ethephon (Ethrel [®] - Rhone-Poulenc)	50 mg l ⁻¹	100 mg l ⁻¹ (sprayed 16 May 1991)
3. Ethephon	100 mg l ⁻¹	500 mg l ⁻¹ (sprayed 16 May 1991)
4. Ethephon	200 mg l ⁻¹	1000 mg l ⁻¹ (sprayed 16 May 1991)
5. KNO ₃ (CP Grade; Kynoch)	1 g 100g ⁻¹	1 g 100g ⁻¹ (sprayed 25 June 1991)
6. KNO ₃	2 g 100g ⁻¹	2 g 100g ⁻¹ (sprayed 25 June 1991)
7. KNO ₃	4 g 100g ⁻¹	4 g 100g ⁻¹ (sprayed 25 June 1991)
8. Urea (low biuret; Kynoch)	1 g 100g ⁻¹	1 g 100g ⁻¹ (sprayed 27 July 1991)
9. Urea	2 g 100g ⁻¹	2 g 100g ⁻¹ (sprayed 27 July 1991)
10. Urea	4 g 100g ⁻¹	4 g 100g ⁻¹ (sprayed 27 July 1991)
11. Paclobutrazol (PP333) (Cultar [®] ; ICI-Kynoch)	500 mg l ⁻¹	500 mg l ⁻¹ (sprayed 6 March 1991)
12. Paclobutrazol	1000 mg l ⁻¹	1000 mg l ⁻¹ (sprayed 6 March 1991)
13. Paclobutrazol	2000 mg l ⁻¹	2000 mg l ⁻¹ (sprayed 6 March 1991)

7.3 RESULTS AND DISCUSSION

The statistical analysis of data was made difficult by genetic variability of sexually propagated trees. The trial site was not ideal, firstly because it was situated on marshy soils with intermittent waterlogging, and secondly, because the site sloped slightly to one side, making the lower portion of the orchard

more vulnerable to waterlogging. Significant differences ($P \leq 0.05$) between replicates indicated this fact. The data were also extremely variable and the coefficients of variation (CV %) were reduced by square root transformation. The CV % of flower data decreased from a mean 215 % to 56.28 %, flush data from an average 107.8 % down to 56.84 %, and flower bud ratings from 210.6 to 54.14 %. However, in spite of the high variability, significant differences between treatments were measured.

7.3.1 Phenology

The most basic necessity for research and management of any tree crop is a phenological model for the crop under given conditions. Management inputs (fertilizers, growth regulator and pesticide applications, irrigation, etc.) applied on a calendar time basis may be ineffective because the tree event (eg. root growth, flowering, etc.) they are supposed to coincide with, or manipulate, could vary in timing from season to season, and could be missed completely. Clearly time and money could be wasted. The term phenology refers to the effect of climate on the growth of a living organism and it may vary between places, seasons, and cultivars of the same crop. Therefore inputs applied on a time basis will be wasted if the phenological stage they are meant to coincide with has passed or must still come (eg. fertiliser applications should be timed to coincide with a period of active root flushing to get maximum efficiency of uptake).

The phenology of cashew (Fig 7.1) in Maputaland is not dissimilar to other subtropical fruit trees such as mango and litchi (Greer, 1990). Cashew trees were generally found to have high growth rates and fill their allotted space relatively quickly. The trees were virtually dormant during the winter months (end of May, June and July) when average temperatures were low. Once temperatures (Fig 7.2) started increasing in spring, there was a generative flush, closely followed by panicle emergence, although some panicles grew simultaneously with the flush, on wood from the previous vegetative flush. The generative flush had not completely hardened by the time main flowering started, although it had hardened off about half way through flowering. It was therefore speculated that the main function of this flush is to provide assimilates for fruit growth and development. This supports Schaper & Chacko (1993) who reported that leaves of the flush associated with the development of the panicles are likely to be the main contributors of carbohydrates to the fruits and pseudofruits. However, some energy produced by this flush may have been available for flowering. Balasimha (1991) was able to measure net photosynthesis, i.e. the sink to source transition, of cashew leaves after a mere eight days of ontogeny, and stored starch levels (Table 7.3) in the trunk only decreased slightly due to this flush.

Although there was some flowering and some flushing throughout the year, this could be ascribed to the genetic variability in the orchards used in the field trials. Cashew panicles are indeterminate and therefore there were always some unopened flower buds together with some open flowers during the life of a panicle, the ratios varying with differing climatic conditions, stage of flowering and severity of blossom disease attack. However unopened panicle production peaked in November / December, and flowering peaked in early January.

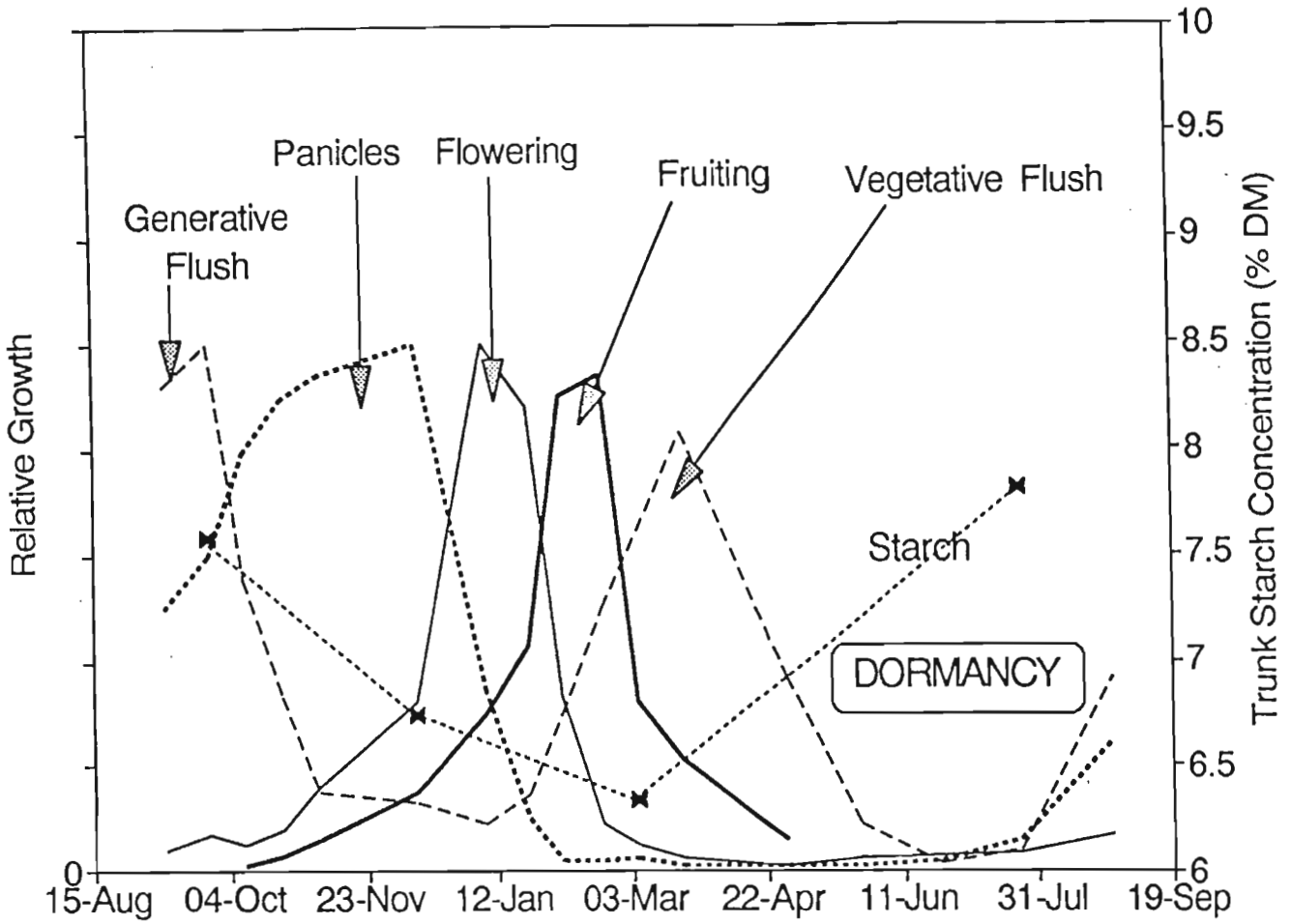


Fig. 7.1. Phenological model for cashew in Maputaland over two seasons (n = 203).

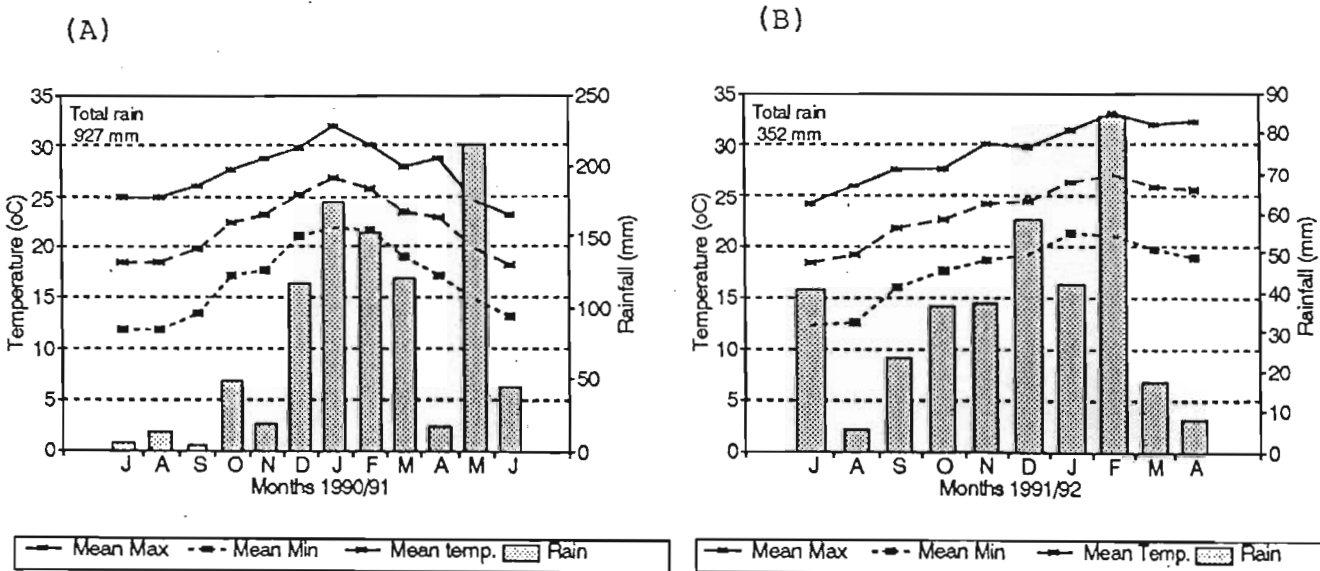


Fig. 7.2. Climatic data for Mosi Estate from (A) July 1990 to June 1991, and (B) July 1991 to April 1992.

Fruit set took place from mid-October onwards and the fruit grew for just over two months before dropping to the ground. The peak fruiting season was in February and early March. Partially coinciding with, but mainly following the harvest, came a strong vegetative flush, which tapered off once the average minimum temperatures started decreasing in autumn (Fig. 7.2). This flush resulted in new growth which matured before becoming dormant. It is speculated that the photosynthates produced by this flush will support flowering the following season, by storing carbohydrates as the trees progress into dormancy. The starch cycle in the trunk was determined over a full year, and this supported this speculation (Fig. 7.1). Starch levels increased during the dormant period, and decreased as the trees became active (vegetative flush) in spring, and declined even further during flowering and fruiting, reaching a minimum near the end of harvest in late summer.

7.3.2 Ethephon

7.3.2.1 Tree Growth

Cashew trees in this trial grew rapidly. During the period from 31 July 1990 to 28 April 1992, mean tree growth of the different treatments ranged from 0.6 m to 1.5 m in height, 0.7 to 1.8 m in canopy diameter, and 11.3 to 15.5 cm in trunk girth.

Ethephon sprays had no significant effect on tree growth at low dosages (10 and 50 mg l⁻¹), but at higher dosages (>500 mg l⁻¹) during the second year, there were visible effects when growth in height (non significant), canopy width and trunk girth (significant at $P \leq 0.01$) were reduced over those of the control (Figs 7.3 & 7.4). Excessive leaf fall resulted from high concentrations of ethephon (500 mg l⁻¹ and 2000 mg l⁻¹) and these concentrations cannot be recommended for application to cashew trees. Pappiah *et al.* (1980) applied ethephon at 50 mg l⁻¹ to increase the ratio of perfect flowers, fruit set and yields, but they did not study the effects of foliar application on timing of flowering. They reported that 150 and 200 mg l⁻¹ ethephon was detrimental to yields, and data from this trial support them. The extent of leaf abscission was probably exacerbated by a 2 to 3 month period of waterlogging after heavy unseasonal rain in May 1991 (Fig. 7.2B). It has long been known that mechanical damage of shoots and leaves (Ross & Salisbury, 1978), and waterlogged roots result in high ethylene concentrations (Jackson & Campbell, 1976) which cause chlorosis of the lower leaves and eventually leaf and flower abscission. These symptoms were also observed on cashew trees which did not receive ethephon sprays but were waterlogged for three months. Some trees eventually died but it is not known whether this was due to the anaerobic conditions, the resultant ethylene build-up, attack by *Phytophthora nicotiana* (shoot and/or root rot), or some combination of the three (probably the latter option).

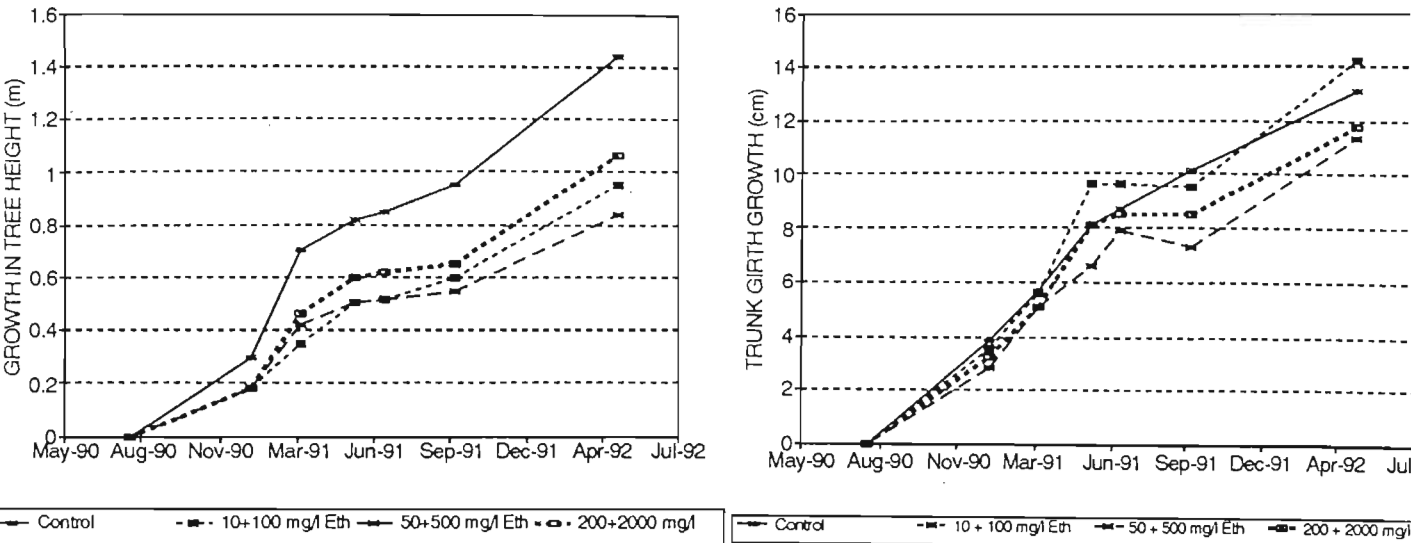


Fig. 7.3. Growth in (A) height, and (B) trunk girth, of ethephon-sprayed cashew trees from 31/7/90 to 28/4/92.

7.3.2.2 Vegetative flushing

According to the literature, flowering follows a generative flush after the dormant winter period (Ohler, 1979). High concentrations of ethephon (500 to 2000 mg l⁻¹) resulted in some growth through winter, most probably resulting from the root: shoot imbalance cause by the high leaf abscission rates (Plate 1) at these concentrations. In extreme cases these trees lost all their leaves and suffered shoot die-back (Plate 2), resulting in shoots resprouting up the trunk and main branches. This also threw the phenology of these trees out of their cycles so that the peak vegetative flushing (Fig. 7.5A) occurred in competition with flowering in January/February 1992, hence the low flowering (Fig. 7.6 B) and yields (Fig. 7.7) from these treatments. At 100 mg l⁻¹, trees did not differ markedly in their flushing from the control trees, with a strong flush in July/August and again after harvest. A strong flush in early November 1991 was not normal and was most probably a reaction to the loss of leaves and flowers in the hailstorm in October.

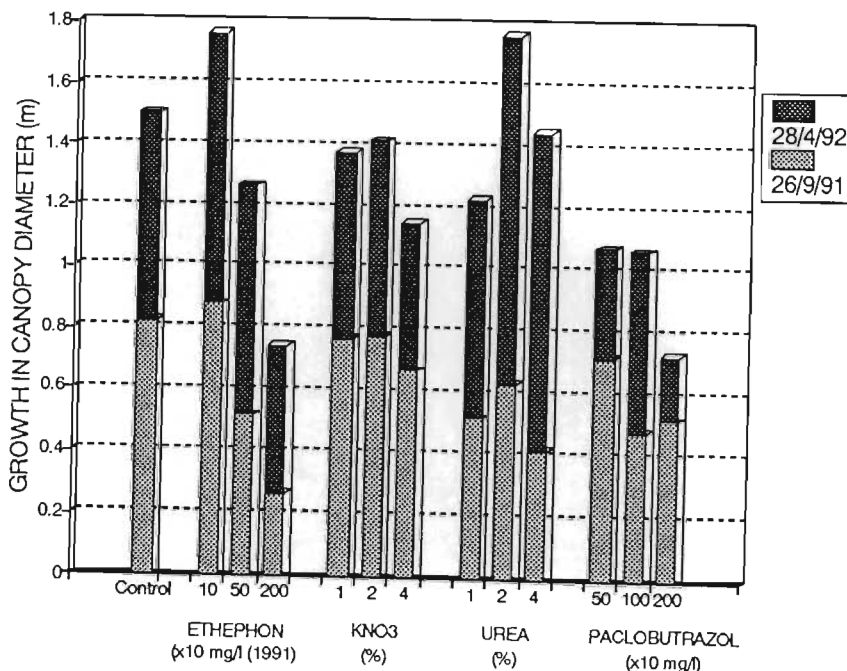


Fig 7.4. Canopy diameter growth of cashew trees at Mosi Estate.

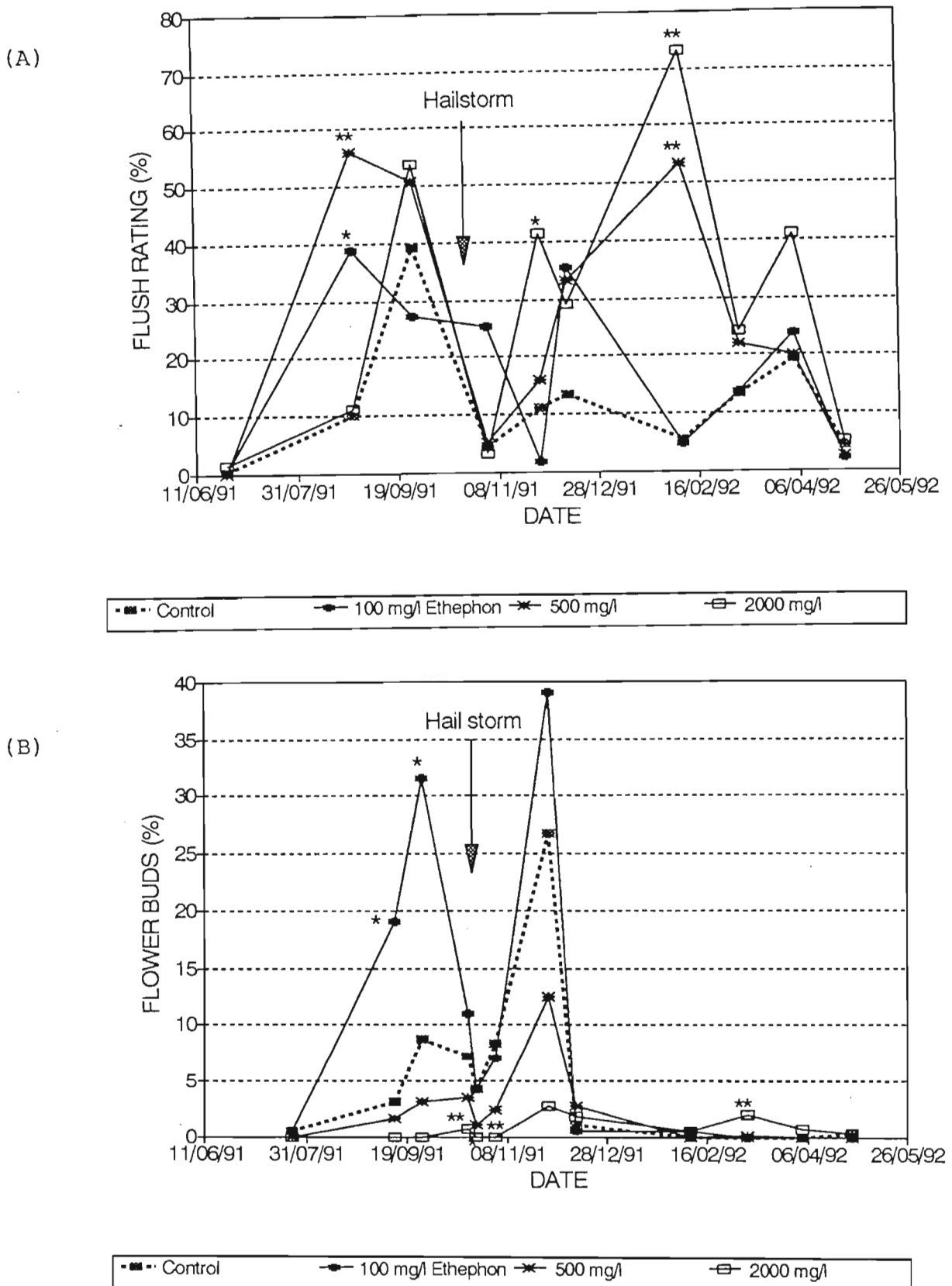


Fig. 7.5. (A) Vegetative flushing and (B) blossom bud ratings of cashew trees sprayed with ethephon. (* and ** indicate significant differences from control at $P \leq 0.05$ and $P \leq 0.01$ levels respectively).

7.3.2.3 Reproductive Growth

During the 1990/91 season average flowering of all ethephon treated trees was less intense than the control trees (Fig. 7.6A) although 200 mg l⁻¹ resulted in the most intense flowering of the ethephon

treated trees. Peak flowering was at the beginning to mid-January 1991, which coincided with peak flowering of the control trees. Interesting to note is that although peak flower intensity (Fig. 7.6A) of trees sprayed with 200 mg l⁻¹ ethephon was lower than that control trees, the yield (Fig. 7.7A) was much higher on the 200 mg l⁻¹ ethephon treated trees. This may either have been due to higher hermaphrodite: male flower ratios (Pappaiah *et al.*, 1980) or possibly higher fruit retention by these trees.

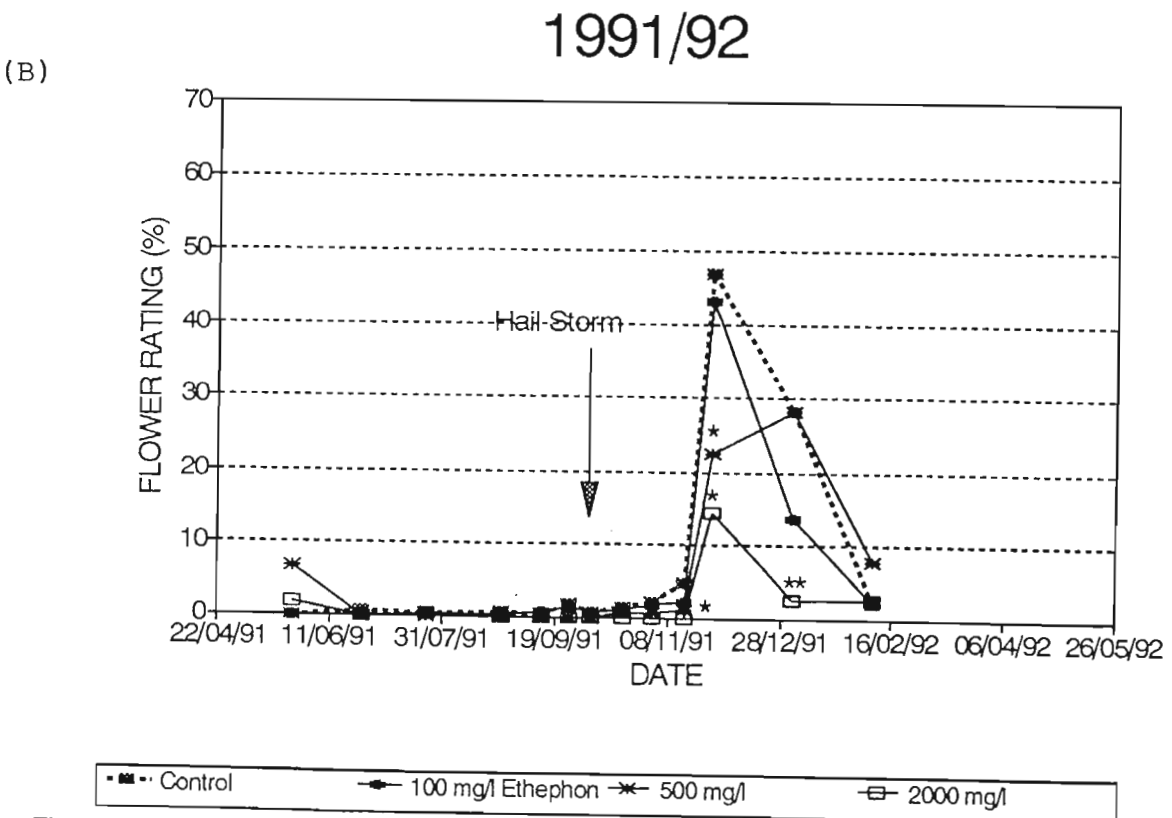
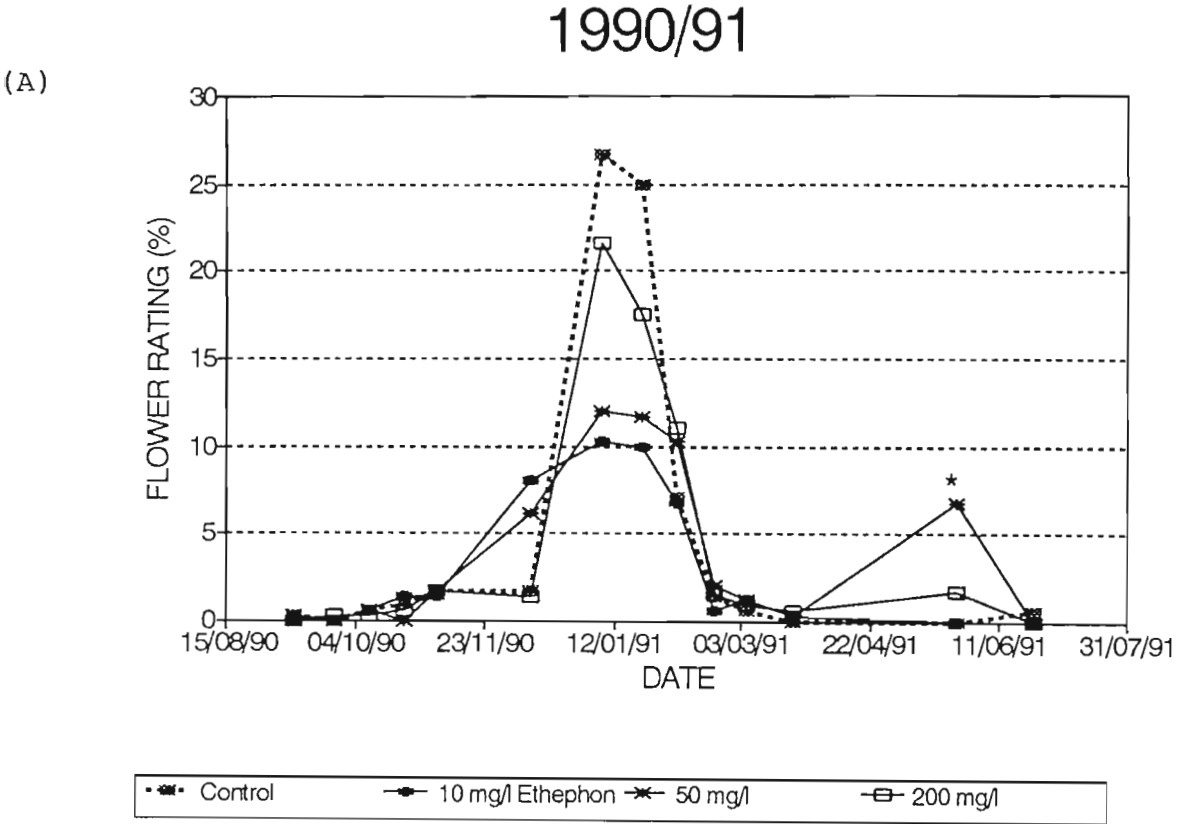


Fig. 7.6 Flower ratings for cashew trees sprayed with ethephon; (A), 1990/91 and (B), 1991/92 season. (* and ** indicate significant differences from control at $P \leq 0.05$ and $P \leq 0.01$ levels respectively)

A similar flowering trend was evident in the 1991/92 season (Fig 7.6B) with control and 100 mg l⁻¹ ethephon trees having similar flowering peaks and intensities. However if flower panicle ratings are scrutinised (Fig.7.5B) there was a peak in mid-September for the 100 mg l⁻¹ ethephon treated trees and it is a pity that the hail storm which followed in October 1991 knocked a major proportion of the flowers off the trees, because this early flowering could have resulted in higher total yields. The 100 to 200 mg l⁻¹ ethephon will have to be further tested. At higher concentrations flowering was less intense and this was reflected in the yield figures (Fig.7.7).

7.3.2.4 Yields

Average total yields in 1990/91 from ethephon-sprayed trees were low compared to the control, except for 200 mg l⁻¹ ethephon, which outyielded the unsprayed trees but not significantly so (Fig. 7.7). The following season, with concentrations increased tenfold, the average total yields from trees treated with 100 mg l⁻¹ (3466.1 g NIS tree⁻¹) were not significantly higher than the control (2813.6 g NIS tree⁻¹). However, at higher concentrations (500 and 2000 mg l⁻¹), the yields were highly significantly lower (Table 7.2) most probably due to the disturbed physiology from excessive leaf loss and the resulting increased stress. This appears to indicate that if there are any beneficial effects of exogenous ethylene application, the optimum ethephon concentration probably lies in the region of 100 to 200 mg l⁻¹. Concentrations higher than 500 mg l⁻¹ ethephon can be ruled out completely as this caused excessive leaf loss. This needs further investigation.

A possible reason for the increased yield may have been due to an increased hermaphrodite : male ratio, or fruit set and retention as reported by Pappaiah *et al.* (1980) who found increased percentage of perfect flowers and improved fruit set (by 47%) over unsprayed controls, from 50mg l⁻¹ Ethrel[®] sprayed at the time of new shoot growth (before flowering). This parameter was not measured due to logistical reasons.

Yield distribution patterns for each treatment were determined during the second season of the study (Table 7.2). At 100 mg l⁻¹ ethephon the yield distribution followed that of the control quite closely and there was no significant difference between these two treatments. The higher concentrations resulted in increasingly later bearing with lower peak yields. During the period from 31 January to 28 February 1992 there were significant ($P \leq 0.05$) differences in mass of nuts harvested between control and 500 to 2000 mg l⁻¹ treatments (Table 7.2). It would have been interesting to see what the yield distribution and total yields could have been, had there been no hailstorm in October 1991 which destroyed the very good early flowering up to that stage.

Table 7.2. Total yields and yield distribution of four-year old cashew trees in Maputaland, during the 1991/92 season, as affected by different chemical applications.

	04-01-92	18-01-92	31-01-93	14-02-92	28-02-92	13-03-92	27-03-92	10-04-92	Total 1991/92
CONTROL	0.0 b ²	133.5 cde	840.3 ab	857.4 abc	545.5 ab	303.3 ab	77.7 ab	35.5 ab	2813.6 abcd
ETHEPHON									
100 mg l ⁻¹	0.0 b	65.0 de	915.1 a	1389.8 ab	802.4 ab	123.9 b	58.0 ab	68.5 ab	3466.1 abc
500 mg l ⁻¹	0.0 b	13.8 de	84.3 cd	252.5 c	614.3 ab	234.2 b	67.0 ab	19.2 b	1285.3 ef
2000 mg l ⁻¹	0.0 b	0.0 e	28.8 d	131.1 c	247.1 b	100.7 b	42.7 ab	5.4 b	525.8 f
KNO₃									
10 g l ⁻¹ (1%)	90.2 ab	340.2 bcd	689.0 abc	1569.0 a	734.6 ab	134.9 b	15.8 b	22.9 ab	3589.5 ab
20 g l ⁻¹ (2%)	97.7 ab	339.8 bcd	597.0 abcd	635.7 bc	256.7 b	179.0 b	64.5 ab	48.7 ab	2121.3 cde
40 g l ⁻¹ (4%)	0.0 b	57.8 de	206.7 bcd	635.0 bc	799.3 ab	136.1 b	32.9 b	25.9 ab	1898.8 def
LOW-BIURET UREA									
10 g l ⁻¹ (1%)	18.8 b	93.5 cde	345.7 abcd	871.1 abc	552.6 ab	181.0 b	159.2 a	87.5 a	2290.4 bcde
20 g l ⁻¹ (2%)	74.8 ab	197.2 bcde	921.3 a	1299.3 ab	570.1 ab	20.4 b	18.8 b	48.8 ab	3185.3 abcd
40 g l ⁻¹ (4%)	2.8 b	107.0 cde	539.7 abcd	606.8 bc	201.7 b	218.1 b	64.1 ab	47.1 ab	1799.4 def
PACLOBUTRAZOL									
500 mg l ⁻¹	183.2 a	779.2 a	741.5 ab	1280.8 ab	1021.0 a	214.1 b	77.5 ab	21.7 b	4135.8 a
1000 mg l ⁻¹	113.3 ab	399.5 bc	765.0 ab	644.8 bc	372.8 ab	533.0 a	96.3 ab	69.2 ab	2880.7 abcd
2000 mg l ⁻¹	232.6 a	473.7 ab	977.9 a	1338.0 ab	510.2 ab	181.5 b	48.2 ab	46.3 ab	3589.5 ab
GRAND MEAN	60.54	230.79	588.65	885.50	556.02	196.93	63.29	42.06	2583.20
LSD (P≤0.05)	159.05	329.28	644.64	788.31	683.71	286.69	120.70	65.38	1460.94
CV (%)	226	123.5	94	77	106	125	164	134	48.8

² Means with the same symbol in each column are not significantly different.

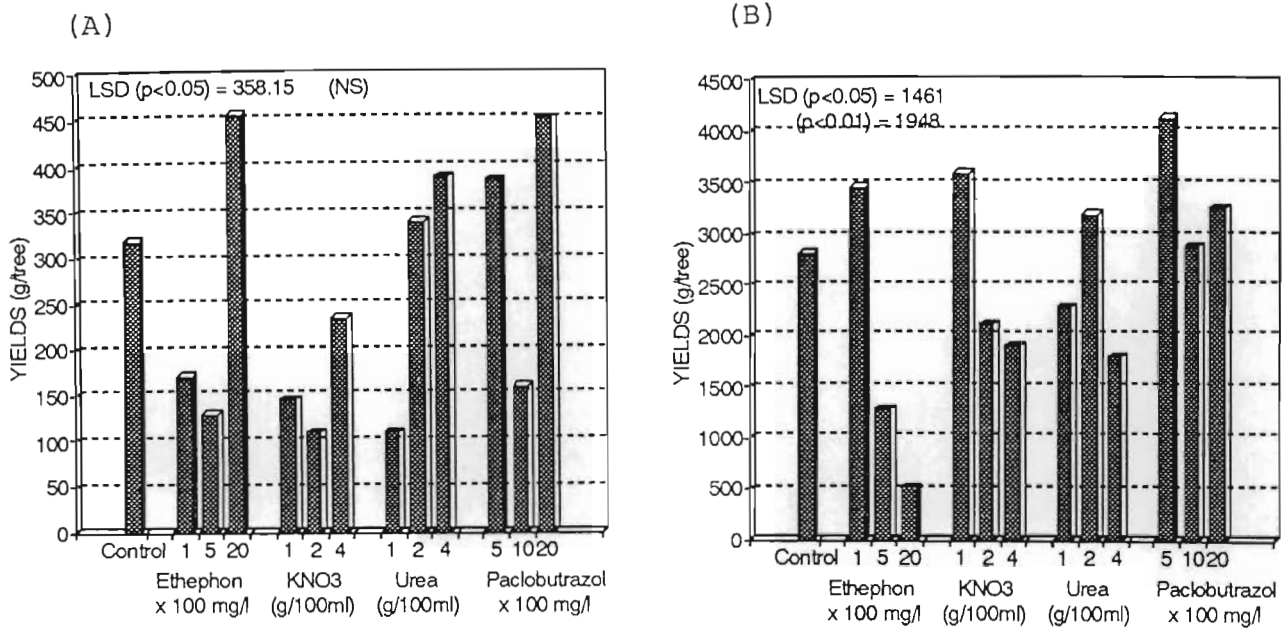


Fig. 7.7. Average total nut in shell (NIS) yields of cashew trees in Maputaland after different chemical applications (A) 1990/91 and (B) 1991/92 seasons.

7.3.2.5 Leaf Ammonium Content

The leaf $\text{NH}_3/\text{NH}_4^+$ content more than doubled (Fig. 7.8) one month after ethephon application in May 1991, and this may have been due to the stress induced by the ethylene. Even the control trees displayed an increase in leaf $\text{NH}_3/\text{NH}_4^+$, which was possibly attributable to the waterlogged conditions from the end of May 1991 to the end of August 1991. In trees treated with the two lower concentrations of ethephon, the leaf $\text{NH}_3/\text{NH}_4^+$ came down from approximately $120 \mu\text{g g}^{-1}$ DM, to 60 to $88 \mu\text{g g}^{-1}$ DM; similar levels to the control trees at the end of September. At 2000 mg l^{-1} ethephon, the trees's physiological responses to stress could not cope and leaf $\text{NH}_3/\text{NH}_4^+$ continued increasing to $273.1 \mu\text{g g}^{-1}$ DM at the end of September, when the last leaf sample was taken.

Any stress which decreases growth or impairs plant health, decreases the rate of protein synthesis, and/or increases protein degradation, which leads to an accumulation of $\text{NH}_3/\text{NH}_4^+$ in the leaves due to excess free amino acids (Rabe, 1990). Ammonia is toxic to plants because it inhibits the production of ATP in the mitochondria and photosynthetic electron transport systems. Usually ammonia is metabolised so rapidly that it never accumulates in plant cells. Carbohydrates supply the reducing energy required for the nitrate reductase system by which ammonia is reduced, as well as the carbon skeletons for the synthesis of many nitrogenous compounds (amines, polyamines) which are produced under stress conditions (Mayer, Anderson & Bohning, 1965; Bray, 1983). A decline in stored carbohydrates in the ethephon-sprayed trees was evident (Table 7.3) and therefore this is a plausible explanation.

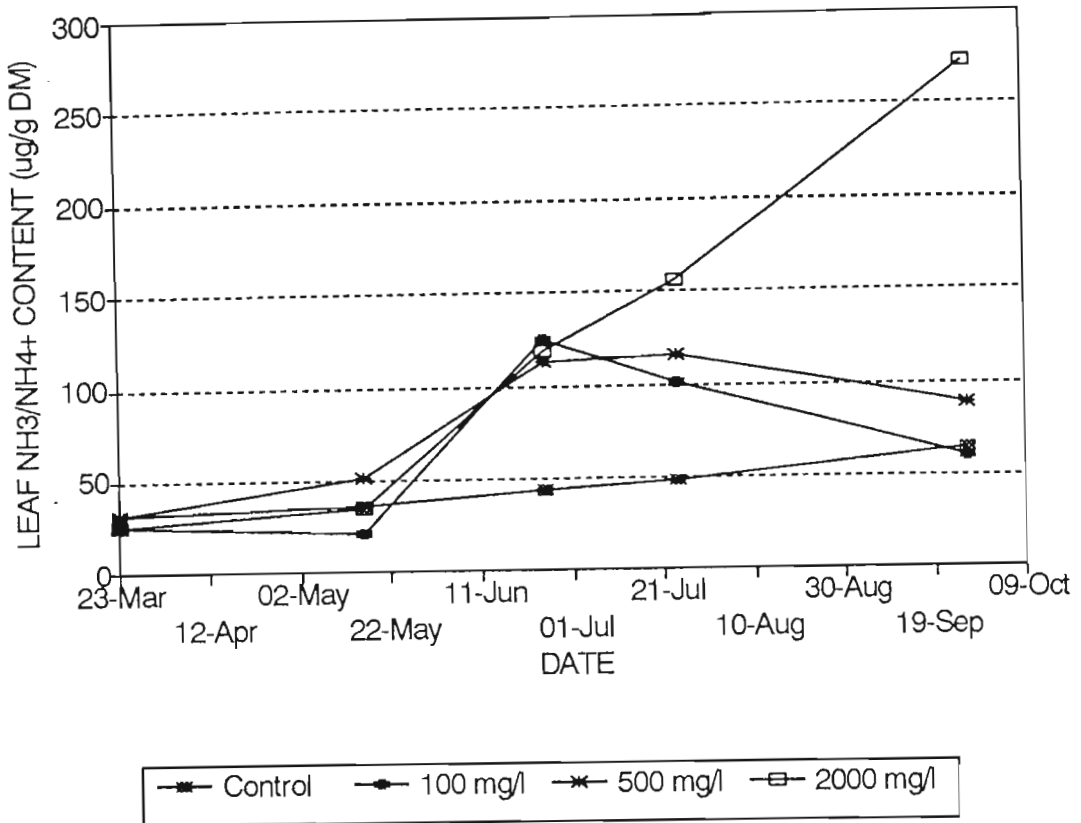


Fig. 7.8. Leaf NH₃/NH₄⁺ from trees sprayed with ethephon on 16 May 1991.

7.3.2.6 Trunk Starch Content

Ethephon applications at 100, 500 and 2000 mg l⁻¹ resulted in gradually declining storage starch content (Table 7.3). Before application, on 12 March 1991, there was no significant difference, i.r.o. mean trunk bark starch content, between the control and ethephon-sprayed trees. However by 24 July 1991, there were significant differences ($P \leq 0.05$) between control trees and trees sprayed with 100 and 500 mg l⁻¹ ethephon. By 26 September 1991, 4 months afterwards, there were significant differences ($P \leq 0.05$) between control trees and 500 and 2000 mg l⁻¹ ethephon trees. While the starch content of the other treatments, including the control trees, had an upward trend until September after which flushing started to use energy, the ethephon-treated trees' starch declined.

A possible explanation for this is that ethylene sprays, as well as the waterlogged conditions for about 3 months which most likely increased endogenous ethylene production (Salisbury & Ross, 1978), put severe stress on these trees, particularly at 500 and 2000 mg l⁻¹ ethephon, with a resultant buildup of leaf ammonia to toxic levels. In order to decrease ammonia concentration in the plant, via the nitrate reductase pathway, and/or the production of amines (less toxic N-compounds), energy supplied by carbohydrates is required (Mayer *et al.*, 1965; Bray, 1983). This is a probable explanation for the decline in stored starch levels observed in the cashew trees treated with high concentrations of ethephon; photosynthetic mechanisms could not supply these carbohydrates due to almost complete

leaf canopy abscission. Under conditions of low carbohydrates, ammonia accumulates in the cells and injury to the plant follows quickly, either due to breakdown of proteins via oxidation in respiration (Mayer *et al.*, 1965; Bray, 1983), or reduced nitrate reductase activity (Mussel & Staples, 1979).

Table 7.3. Trunk bark starch concentrations of bearing cashew trees in Maputaland, as affected by different chemical sprays.

Treatment	Sampling Date (1991)				
	12 March 1991	16 May 1991	24 July 1991	26 Sept 1991	28 Nov 1991
Control	7.12 ab	7.67 abc	8.21 ab	7.63 ab	7.16 a
Ethephon					
100 mg l ⁻¹	6.79 ab	6.83 c	5.49 d	5.60 bcd	4.34 b
500 mg l ⁻¹	7.49 a	7.33 abc	5.68 cd	3.64 d	3.37 b
2000 mg l ⁻¹	8.47 a	8.63 abc	6.16 bcd	4.64 d	4.00 b
KNO₃					
1 %	7.40 a	7.88 abc	8.57 a	7.82 a	7.56 a
2 %	7.35 a	7.30 abc	8.12 ab	9.56 a	7.86 a
4 %	5.03 b	6.51 bc	7.71 abc	5.28 cd	5.04 b
Urea					
1 %	7.18 ab	7.61 abc	8.36 a	8.93 a	8.16 a
2 %	7.12 ab	7.57 abc	8.20 ab	7.44 abc	7.08 a
4 %	7.40 a	7.89 abc	9.22 a	9.28 a	8.99 a
Paclobutrazol					
500 mg l ⁻¹	7.20 ab	7.50 abc	8.11 ab	7.61 ab	7.30 a
1000 mg l ⁻¹	8.53 a	8.81 ab	9.30 a	9.22 a	8.51 a
2000 mg l ⁻¹	8.28 a	9.05 a	8.72 a	9.02 a	8.04 a
GRAND MEAN	7.33 ab	7.71 abc	7.83 abc	7.36 abc	6.72 ab
LSD (P≤0.05)	2.218	2.322	2.176	2.613	1.961
CV (%)	26.15	26.10	24.05	30.75	25.25

7.3.3 Potassium Nitrate

7.3.3.1 Tree Growth and Development

There were highly significant differences ($P \leq 0.01$) between control and KNO₃ treated trees in tree height growth (Fig. 7.9A), but not in trunk girth (Fig. 7.9B) nor canopy diameter growth (Fig. 7.4). KNO₃ also had no significant effect on vegetative flushing (Fig. 7.10A). Panicle emergence of KNO₃ sprayed trees started slightly earlier than controls (Fig. 7.10B) but the high KNO₃ concentrations seemed to have a detrimental effect on subsequent flowering (Fig. 7.11B). Early flowering (September 1990) of 1% KNO₃ during the first season was significantly ($P \leq 0.05$) higher than control trees (Fig. 7.11) but otherwise there was no significant difference in flowering between KNO₃ sprayed trees and control trees.

The use of KNO₃ has been found to promote flowering in mango in the tropics, but not in the subtropics

(Bondad & Linsangan, 1979; Mosqueda Vasquez *et al.*, 1982; Winston & Wright, 1986), but the mechanism by which flowering is triggered by KNO_3 is not well understood. It is known that the N-reserve status plays a role in flower bud initiation. Faby & Naumann (1986) reported that flower bud induction was poor when no nitrogen was applied, but when N-reserves were high, flower buds opened earlier and fruit set was improved. A similar response was found by Hake & Lovatt (1987) in citrus where foliar applications of low-biuret urea increased leaf ammonium levels, which in turn led to increased floral intensity. Trewavas (1983) noted that nitrate can terminate dormancy of flower buds, and it is possibly this dormancy-breaking action that promotes flowering in difficult-to-flower mango cultivars. A further discussion of the influence of nitrogen on flowering is given in section 7.3.4.5.

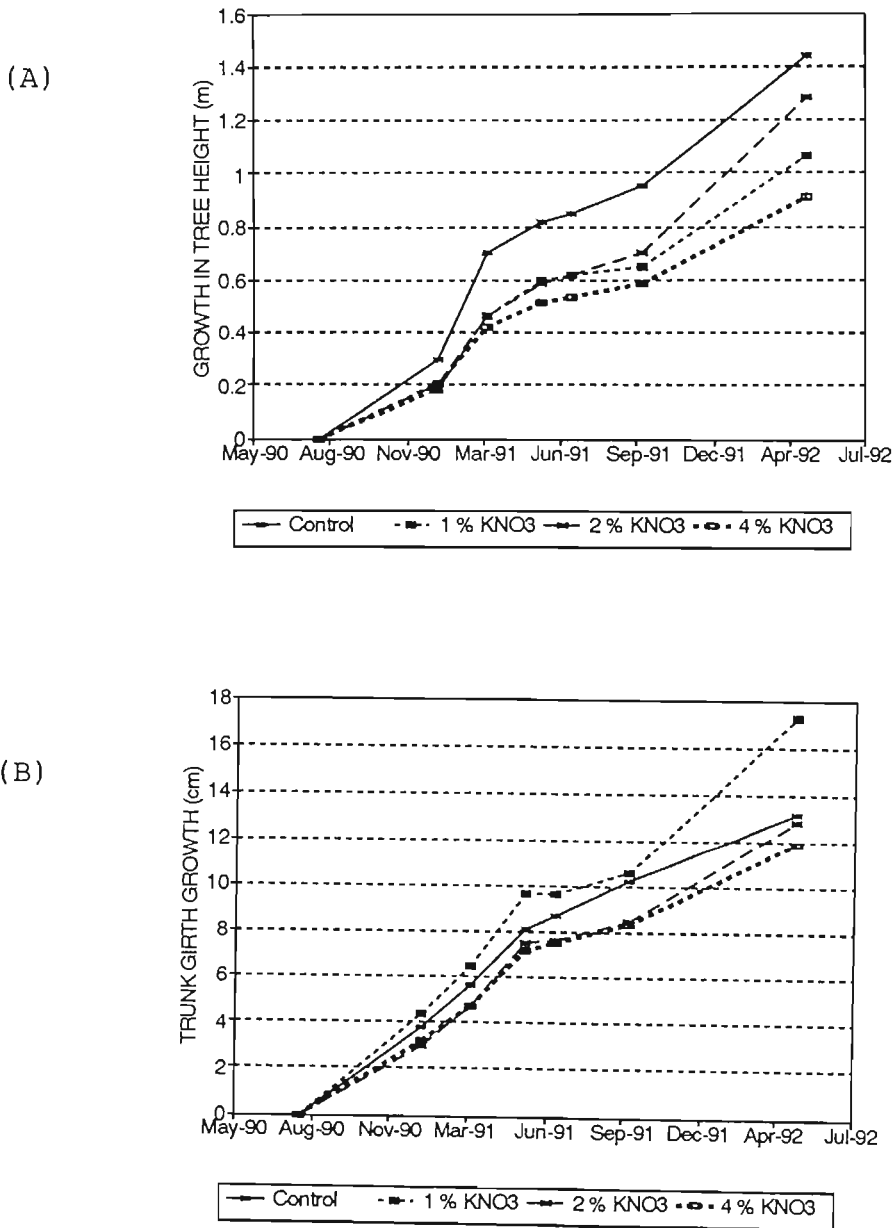


Fig 7.9. Growth in (A) height, and (B) trunk girth, of KNO_3 -sprayed cashew trees from 31/7/90 to 28/4/92.

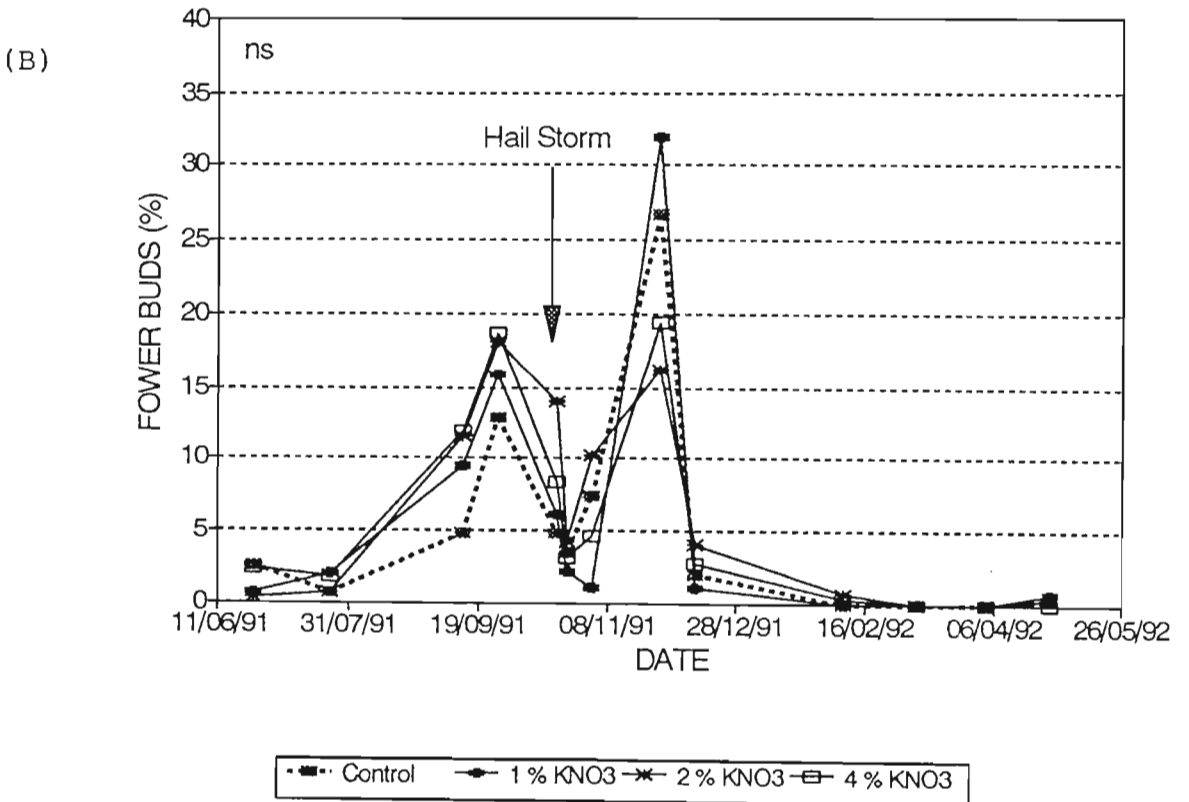
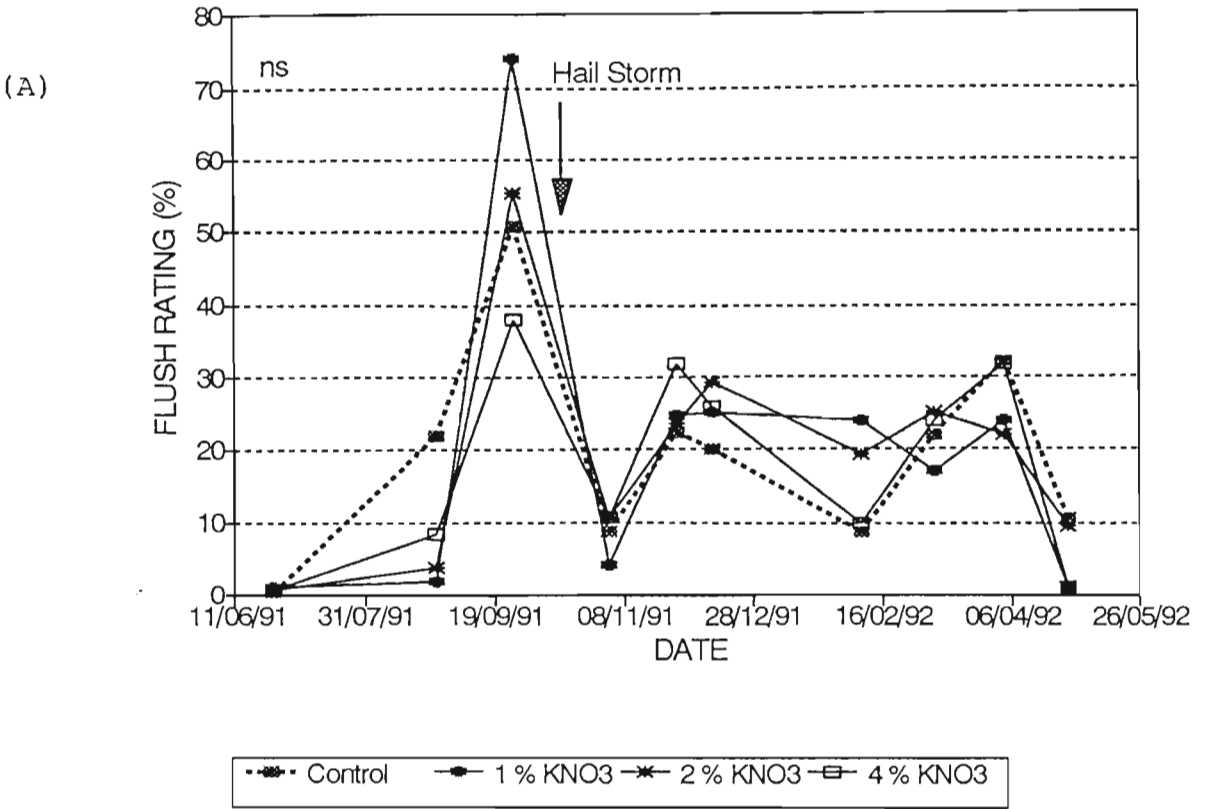
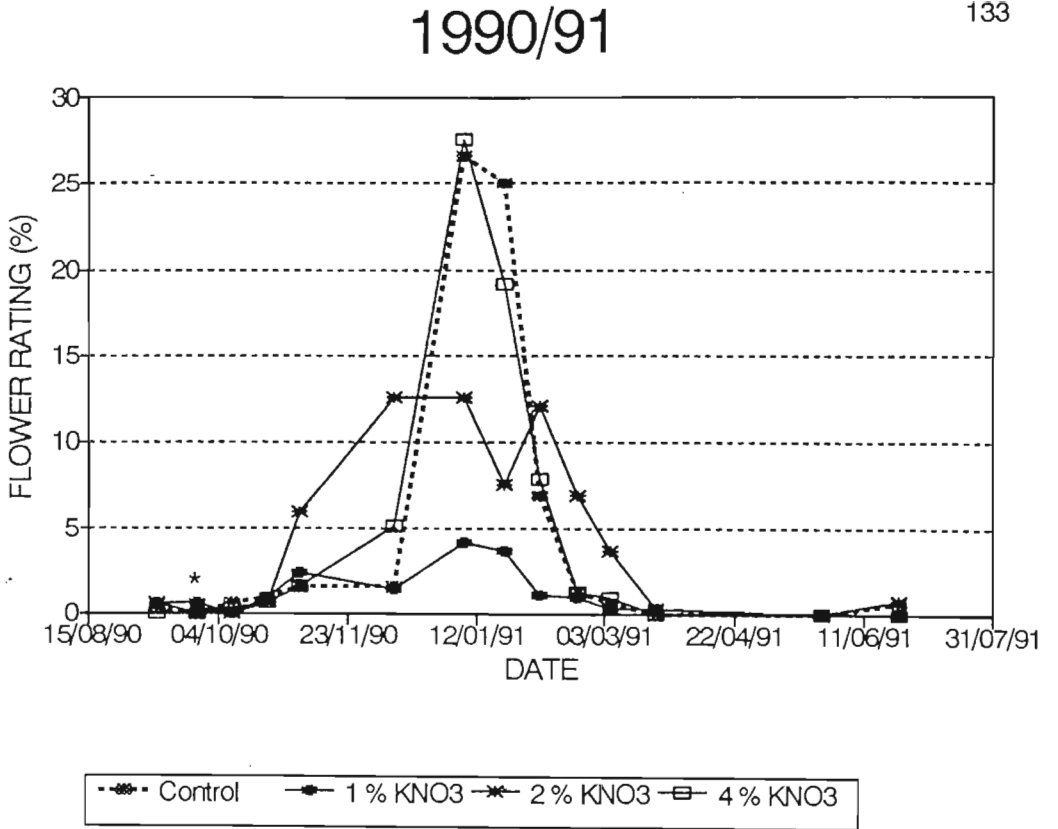


Fig. 7.10. (A) Vegetative flushing and (B) blossom bud ratings of cashew trees sprayed with KNO_3 . Data were square root transformed ($x'=\sqrt{x+0.5}$) for statistical analysis and means were then detransformed for presentation.

(A)



(B)

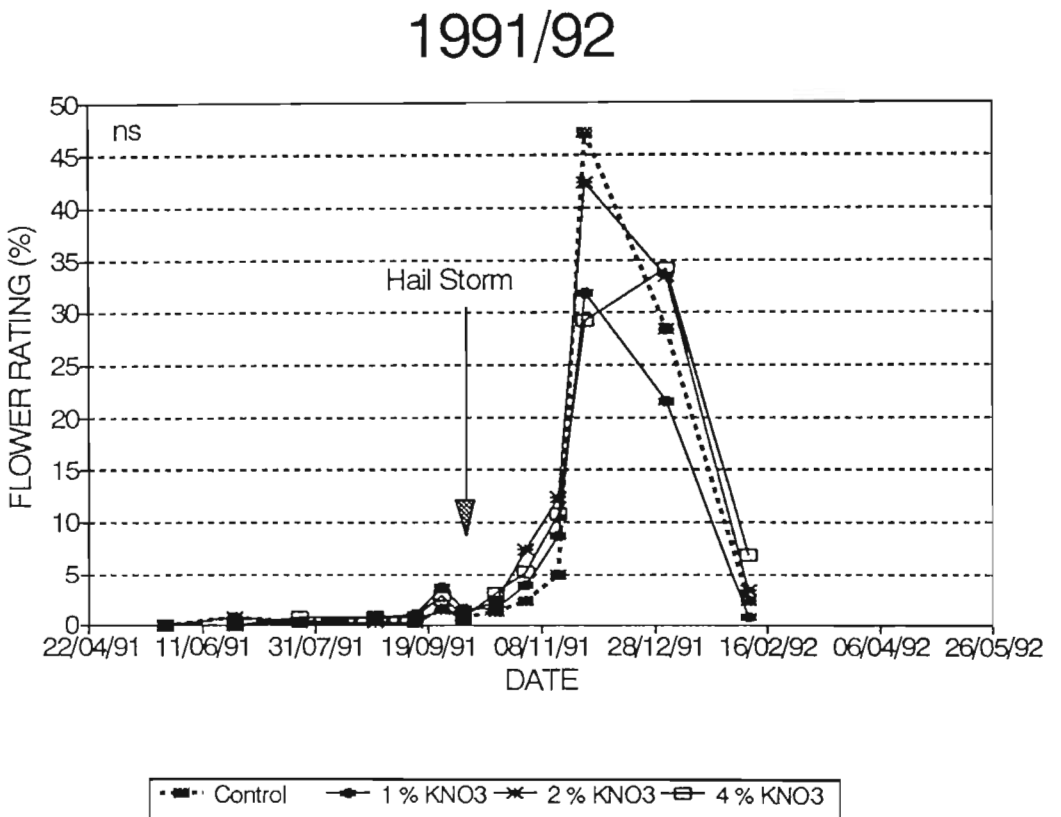


Fig. 7.11. Flower ratings for cashew trees sprayed with KNO_3 (A) 1990/91, and (B) 1991/92. Data were square root transformed ($x' = \sqrt{x + 0.5}$) for statistical analysis and means were then detransformed for presentation.

7.3.3.2 Yields

Although yield differences were not significant from controls, 1 g KNO_3 100 ml⁻¹ resulted in the second

highest average yield (3589.5 g NIS tree⁻¹ cf. 2813.6 g NIS tree⁻¹ from control) of all treatments during the second season (Table 7.2). This concentration significantly ($P \leq 0.05$) outyielded the 4g KNO₃ 100 ml⁻¹ treatment (1897.8 g NIS tree⁻¹) by 89 %.

The timing of the yield is of relatively little consequence to the cashew producer, compared to total yields, because of the long periods that raw cashew nuts can be stored for, after desiccation. Therefore there is no need for a peak cashew processing season, and it can occur throughout the year. This has a stabilising effect on raw cashew nut prices. What is important, however, is the timing of flowering and early fruit growth, because, if these events coincide with wet periods, the decreased yields due to attack by fungal diseases can be highly significant.

7.3.3.3 Leaf Ammonium Content

One month after spraying the cashew trees with KNO₃, there was an increase in leaf NH₃/NH₄⁺ from about 40 µg g⁻¹ DM to between 80 and 90 µg g⁻¹ DM., and this was consistent with all three treatments (Fig. 7.12). However, by 26 September, three months afterwards, the levels had dropped to those similar to the control trees around 70 µg g⁻¹ DM, with the exception of the highest concentration (40 mg KNO₃ l⁻¹) which remained at 88.5 µg g⁻¹ DM. It appears as if the nitrate reductase pathway could not cope with the sudden increase in NO₃, the product of this pathway, possibly because of a feedback mechanism to slow down the reaction, a shortage of nitrate reductase, or some other unknown factor. This could have resulted in the build-up of ammonia noticed in the leaves of the KNO₃ treated trees. In the trees sprayed with 1 % and 2% KNO₃, the nitrate reductase pathway seems to have brought NH₃/NH₄⁺ levels to more normal levels. It must also be kept in mind that even the control trees experienced a steadily increasing NH₃/NH₄⁺ curve, possibly due to stress imposed by waterlogging and/or cooler temperatures (Fig. 7.2) during this period.

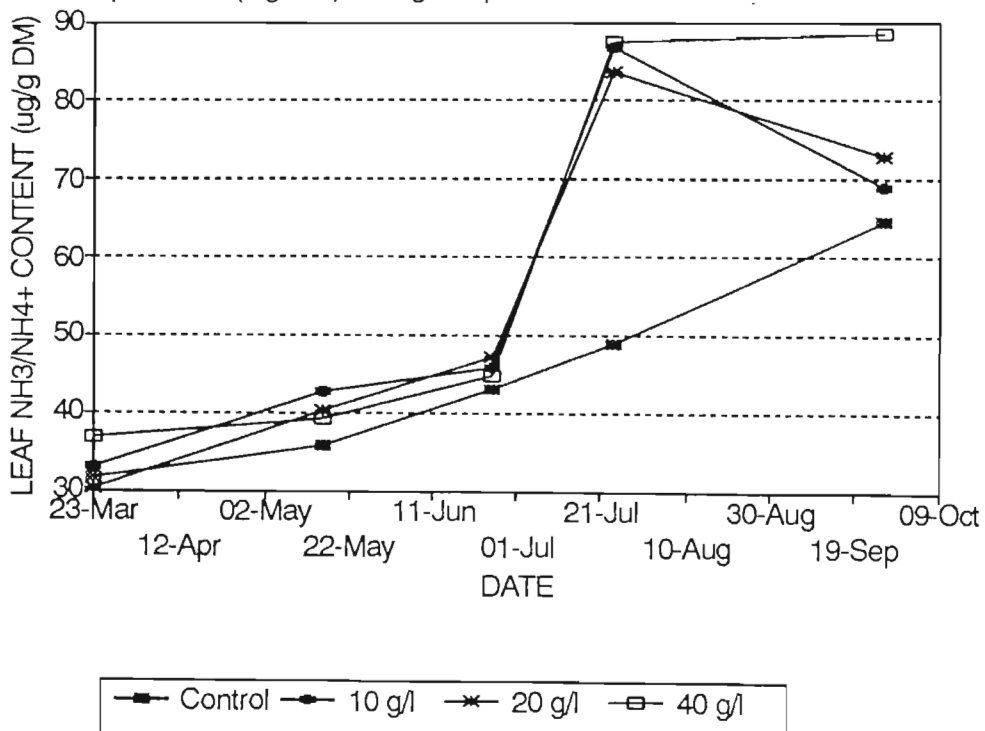


Fig. 7.12. Leaf NH₃/NH₄⁺ levels for 1991 of trees sprayed with KNO₃ on 25 June 1991.

7.3.3.4 Trunk Starch Content

The increased leaf $\text{NH}_3/\text{NH}_4^+$ in the 4 % KNO_3 -treated trees (Fig. 7.12) coincided with a significant decrease ($P \leq 0.05$) in starch levels in the trunk (Table 7.3), indicating that stored energy was being used at a much greater rate than in trees with lower concentrations of KNO_3 . The starch (energy) was most likely being used to drive the nitrate reductase pathway, as well as to supply the carbon chain for the amines, amides, polyamines, etc., apart from the normal metabolic processes in the tree.

7.3.4 Urea

7.3.4.1 Tree Growth, Development and Yields

Urea was applied on 31 July 1990 and again on 27 July 1991. The growth check in height (Fig. 7.13A) during the winter became more marked with increasing urea concentration, although the overall growth rates of urea-sprayed trees were not significantly different from the controls. Trees sprayed with 10 g urea l^{-1} experienced hardly any growth check at all, possibly due to more optimum N levels than the control trees and the trees treated with more concentrated urea. Tree height growth of 20 and 40 g urea l^{-1} trees was significantly less than controls from 16 March 1991 onwards (Fig. 7.13A). Trunk girth growth is usually a more reliable indicator of tree vigour, than height or canopy diameter measurements and for this parameter there were no significant differences over time (Fig 7.13B).

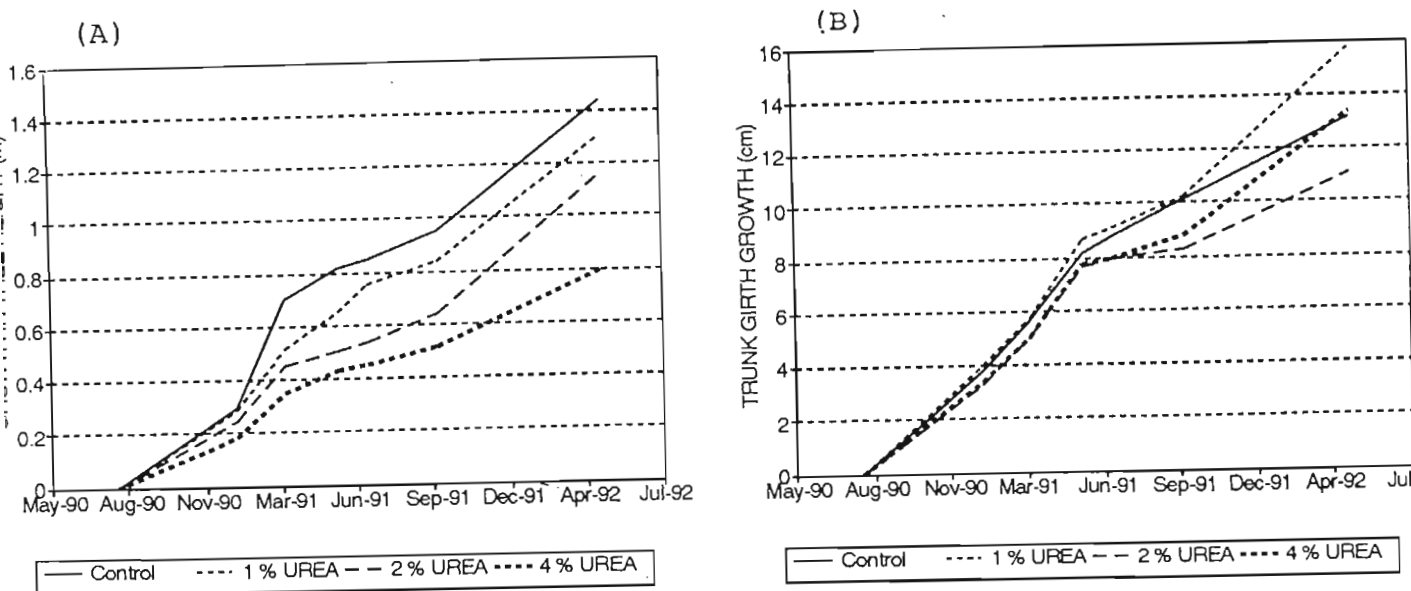


Fig 7.13. Growth in (A) height, and (B) trunk girth, of cashew trees from 31/7/90 to 28/4/92 sprayed with low-biuret urea on 31-07-90 and, repeated on 27-07-91.

During the 1990/91 season the urea sprayed trees flowered poorly compared to controls (although not significantly so) and it was thought that excessively high nitrogen counteracted the flowering stimulus. Therefore a closer look at the vegetative to reproductive competition during the following year was made. Scrutiny of the flush and flower ratings reveals that there was a coincidence of flushing (Fig. 7.14A) and peak flowering (Fig. 7.15B) during the period from December 1991 to February 1992, with 1% urea having the strongest flush. This may have resulted in competition for reserves and assimilates, and hence the poorer flowering on urea-sprayed trees. The poor flowering in 1990/91 did not result in significantly poorer yields (Fig. 7.7a), but during the 1991/92 season yields of 1% urea (18.6 % less than

control) and 4% urea (36.1 % less than control) treated trees were poorer on average than controls (2813.6 g NIS tree⁻¹), but not significantly so.

Trees with 2 % urea had earlier flowering than controls and the lowest flushing (Fig. 7.14A) during peak flowering (November/December 1991), and this resulted in the highest yield (3185.3 g NIS tree⁻¹; 13.2% above control) (Table 7.2) of the urea-treated trees. There was no significant difference in panicle production (Fig. 7.14B) between the urea treatments and the control. It could be speculated that the competition between vegetative and reproductive growth at peak flowering in 1991/92 was a partial cause of these poor yields.

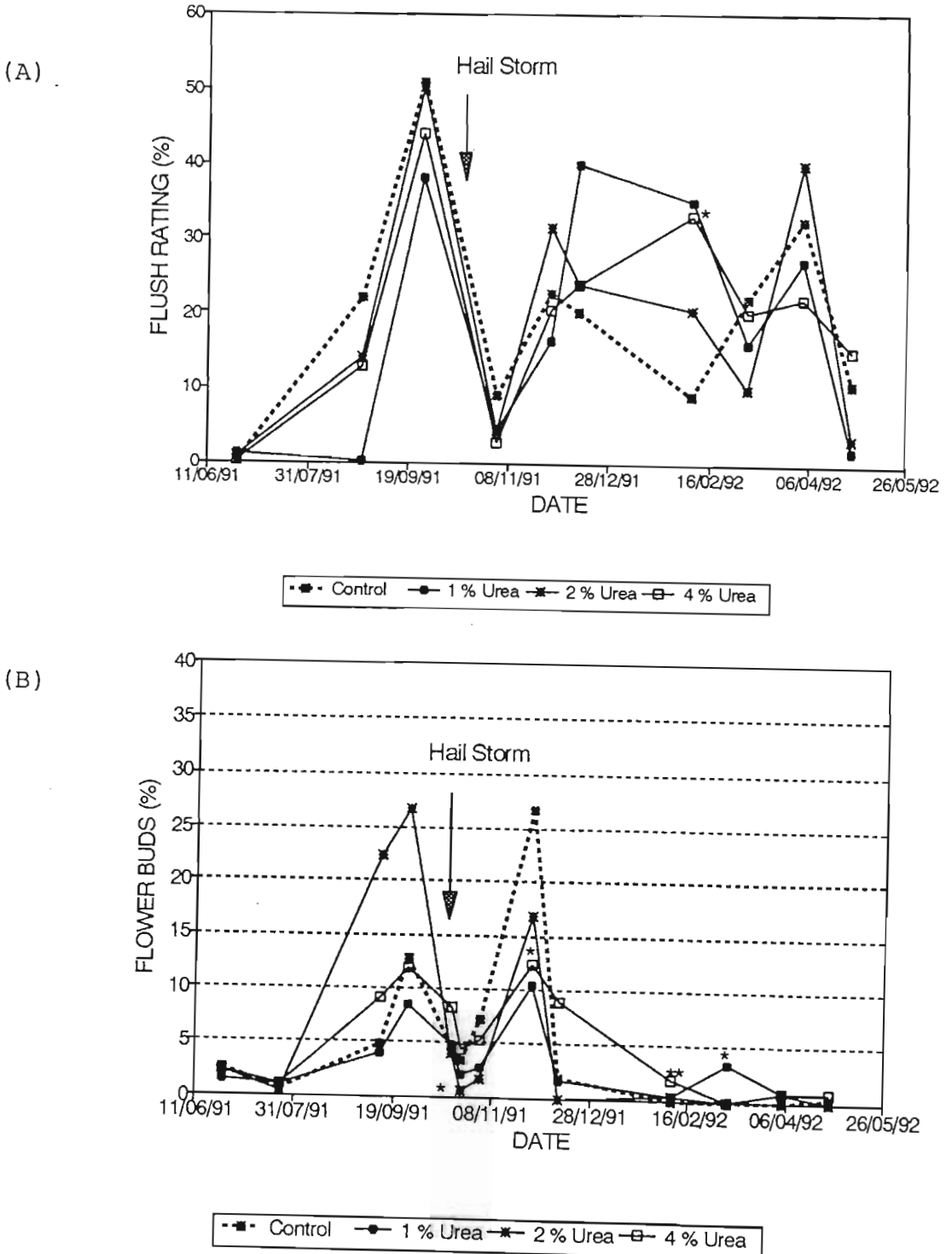
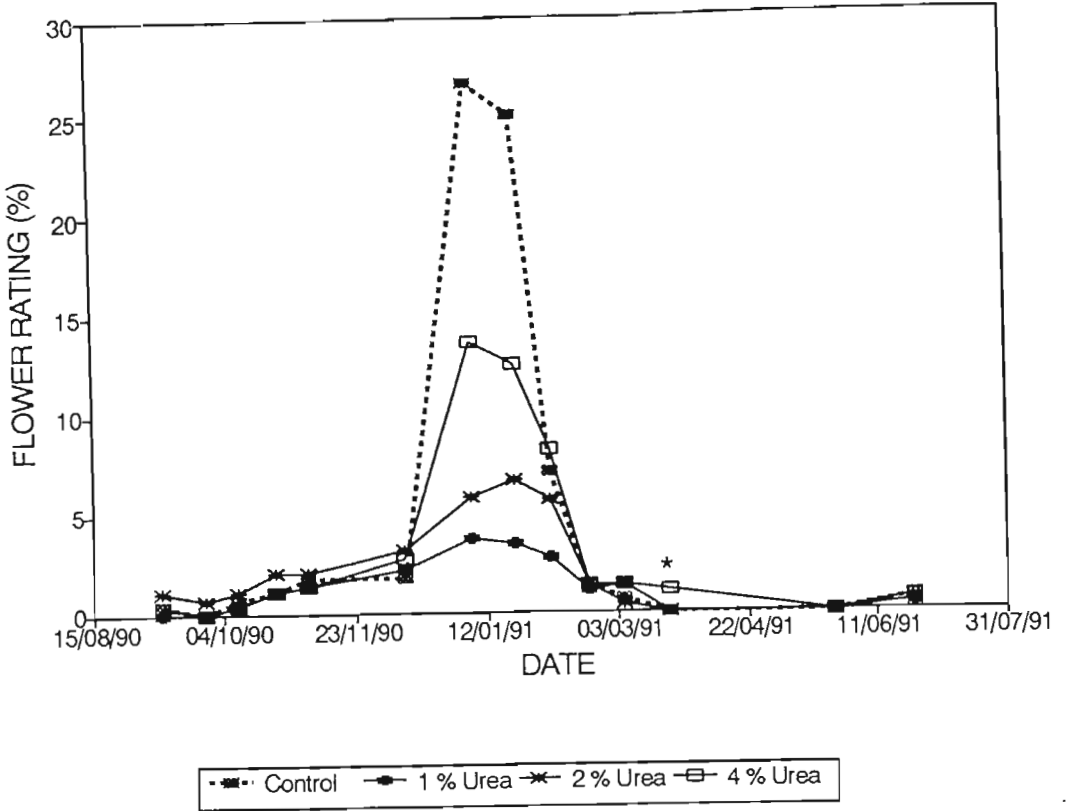


Fig. 7.14.

(A) Vegetative flushing and (B) blossom bud ratings of cashew trees sprayed with urea. Data were square root transformed ($x'=\sqrt{x+0.5}$) for statistical analysis and means were then detransformed for presentation. (* and ** indicate significant differences from control at $P\leq 0.05$ and $P\leq 0.01$ levels respectively).

(A)



(B)

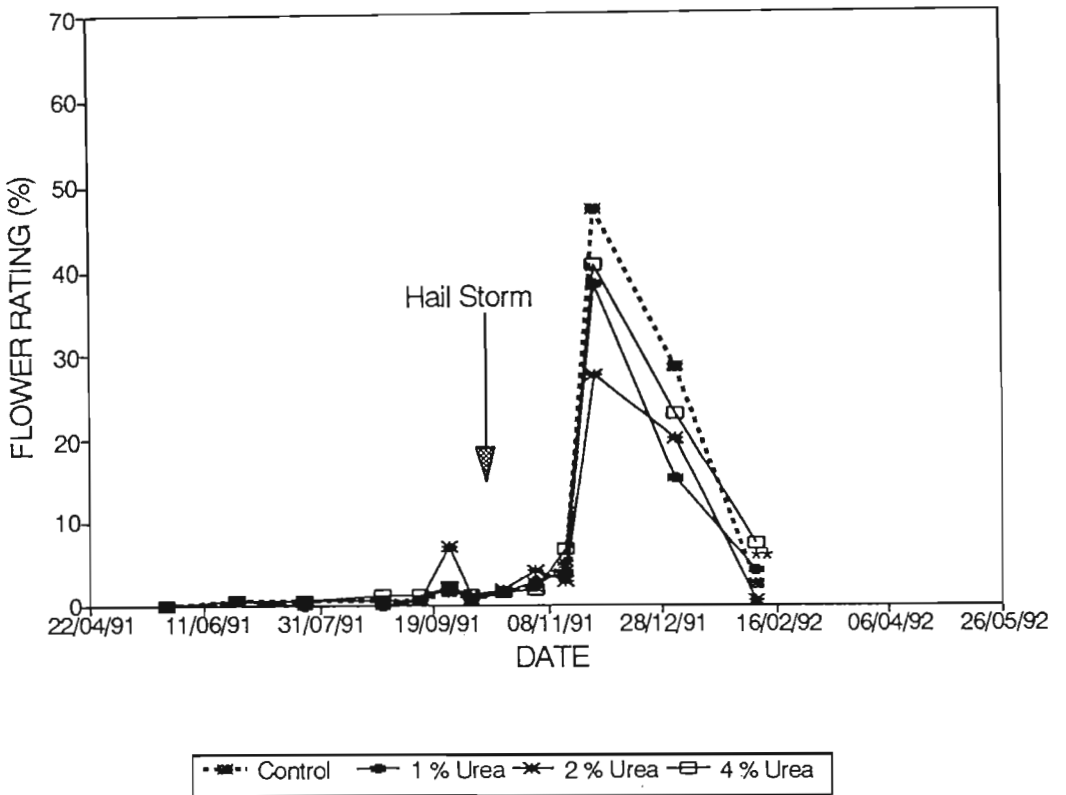


Fig. 7.15.

Flower ratings for cashew trees sprayed with urea (A) 1990/91, and (B) 1991/92. Data were square root transformed ($x' = \sqrt{x+0.5}$) for statistical analysis and means were then detransformed for presentation. (* and ** indicate significant differences from control at $P \leq 0.05$ and $P \leq 0.01$ levels respectively).

7.3.4.2 Leaf Ammonium Content

It was expected that urea sprays would increase the leaf $\text{NH}_3/\text{NH}_4^+$, and this was evident from the data (Fig. 7.16). Unfortunately, time did not allow for later leaf $\text{NH}_3/\text{NH}_4^+$ analysis so that these levels could be monitored over a longer time. Leaf $\text{NH}_3/\text{NH}_4^+$ levels, however, were investigated in a glasshouse trial to test the effects of urea on flowering and growth of young cashew trees (Chapter 5). The increased leaf $\text{NH}_3/\text{NH}_4^+$ appeared to influence the flowering of the treatment receiving 20g urea l^{-1} by resulting in early panicle emergence (Fig. 7.14A), but this early flowering was also destroyed by the untimely hail storm in October 1991, and it is not known whether this early panicle emergence would have resulted in any significant flower intensity or yield increases. However, it did look promising at the time and deserves further investigation.

The rationale behind spraying urea, is based, as for KNO_3 , on increasing the N levels in the leaves, with corresponding improvements in flowering and fruit set (Faby & Naumann, 1986), as discussed in par. 7.3.3.1. Hake & Lovatt (1987) found that foliar applications of low biuret urea increased leaf ammonium levels, which in turn led to increased floral intensity in citrus. This flowering response was further amplified by water-deficit stress (Hake & Lovatt, 1987), and by low-temperature stress (Zheng & Lovatt, 1987). Urea applications during water-stress periods doubled the ammonium level of leaves and significantly increased (by 258%) the intensity of flowering. It increased flower intensity by 255% for trees subjected to low temperatures. Rabe & Lovatt (1986) also showed increases in leaf $\text{NH}_3/\text{NH}_4^+$ from P deficiency in squash and rough lemon, and Lovatt (1986) reported increased ammonia from salinity stress. This led Rabe & Lovatt (1986) and Rabe (1990) to suggest that since environmental stress, which was usually a prerequisite for flowering in many commercial species, resulted in higher endogenous ammonia levels, the exogenous application of chemicals which increased leaf $\text{NH}_3/\text{NH}_4^+$ may provide the opportunity to regulate this process much better by "artificially" inducing stress.

Trewavas (1983) has a different theory on the role of nitrogen compounds in flower initiation. The mechanism he proposes involves nitrate. He concludes that the photoperiodic stimulus sensed in the leaves, results in a dramatic decline in nitrate. He proposes this to be as a result of the photoperiodic control of leaf nitrate reductase, which has been reported (Srivastava, 1980). The reduction of available nitrogen and its release from leaves under photoperiodic control is thought to increase flowering.

The findings of Hake & Lovatt (1987) and Zheng & Lovatt (1987) concerning the induction of flowering in citrus can be looked at from Trewavas' point of view. Increases in protein and soluble amino acid contents are well known in times of stress. It is thus possible that these accumulations, as well as those from the foliar sprays of urea, can be induced to move out of the leaves due to the mechanism

of photoperiodic control, as viewed by Trewavas. They could then move to the sites of flower bud initiation, these sites now having a greater capacity to respond to inductive stimuli. Also, any flower buds already initiated now have a readily available source of nitrogenous compounds.

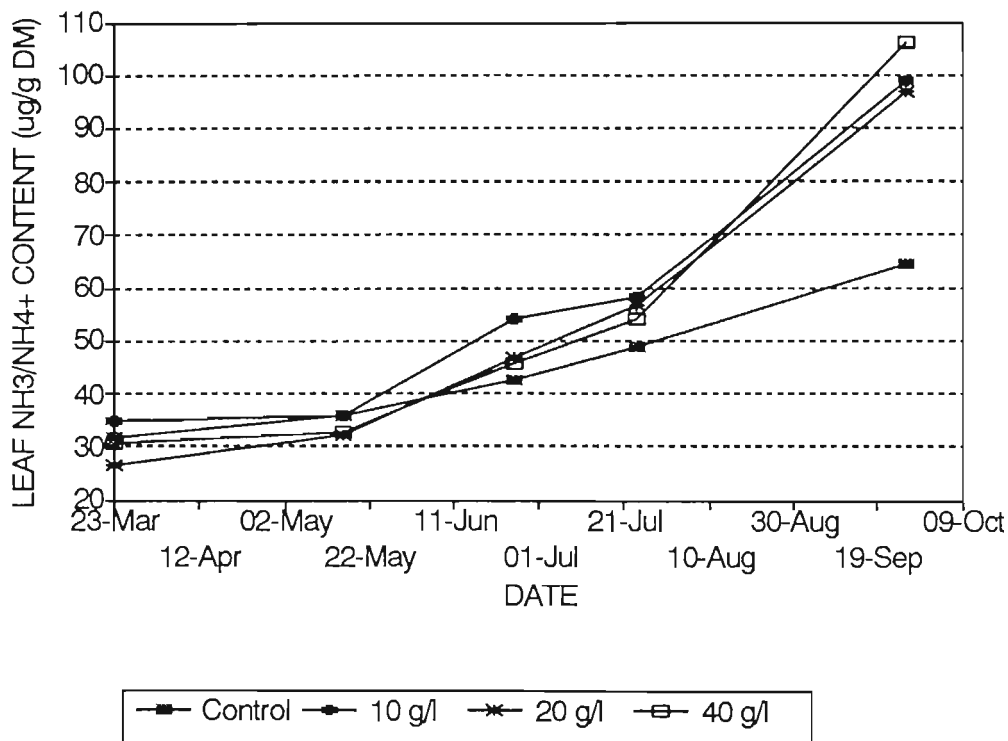


Fig. 7.16. Leaf NH₃/NH₄⁺ levels for 1991 of trees sprayed with urea on 27 July 1991.

7.3.4.3 Trunk Starch Content

Trees treated with 2% urea, displayed almost identical mean starch levels to the control trees (Table 7.3), while starch levels of 1 and 4% remained high after growth had started in late spring-summer. It appears as if the early flower panicle emergence and relatively high yields of the 2% urea trees utilised these reserves. The expected depletion of trunk reserves by simultaneous flowering and flushing of the 1 and 4% urea trees was not evident, but yields from these trees were relatively low and therefore may not have drawn on stored reserves as much as the high yielding treatment. However, reserves from twigs and branches may have been utilised, and/or the mobilisation of the trunk starch may have been uncoupled in some way.

7.3.5 *Paclobutrazol*

7.3.5.1 Tree Growth

Paclobutrazol has the effect of discouraging tree growth, while promoting flowering and these effects were quite evident in this trial. All concentrations (500, 1000 and 2000 mg l⁻¹) resulted in significantly less ($P \leq 0.01$) growth in height than controls during the first year, (500 and 1000 mg l⁻¹ were significantly

less ($P \leq 0.01$) after only 6 months) (Fig. 7.17A), and this was continued through the second year. Canopy diameter growth (Fig. 7.17B) was less than controls, but only the highest concentration significantly so ($P \leq 0.05$) after 2 years. This is a desirable trend if trees are to be planted at high densities. Growth in trunk girth (Fig. 7.18B) was not significantly affected by paclobutrazol, but all the trees sprayed with paclobutrazol had more pronounced growth checks directly after spraying (March to June 1991). This may have forced the trees into a semi-dormant state and resulted in good flower induction, the results of which are seen in Fig. 7.19.

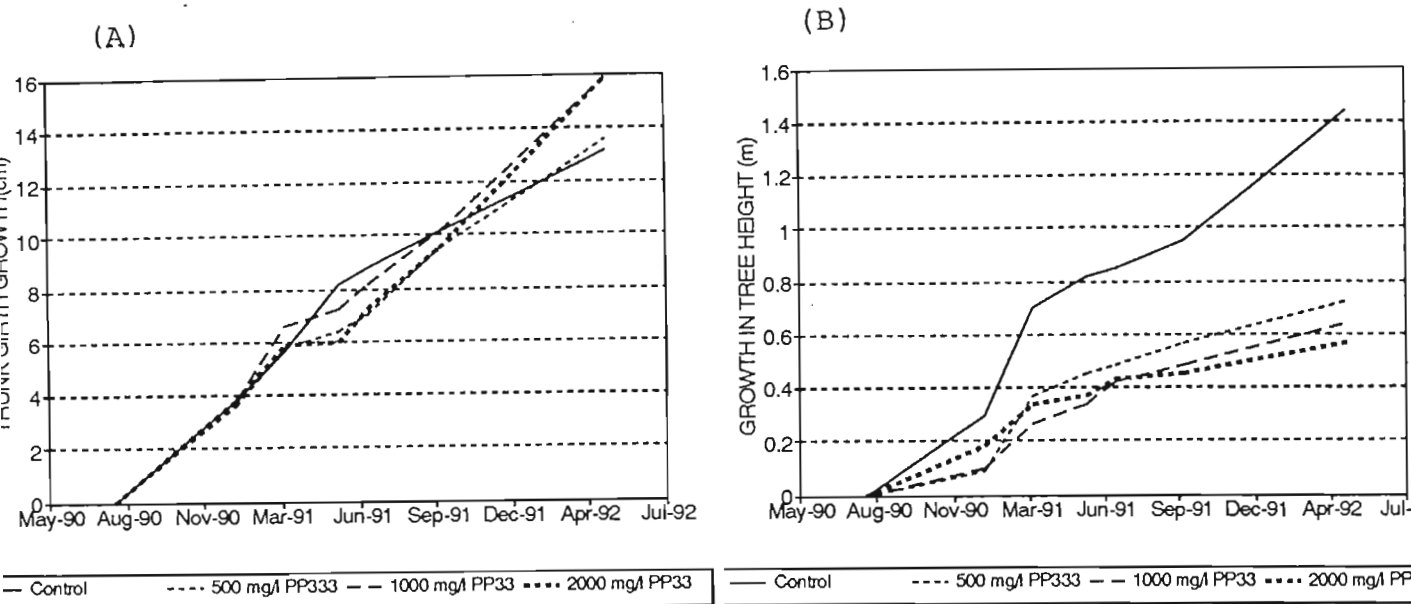


Fig 7.17. Growth in (A) height, and (B) trunk girth, of cashew trees from 31/7/90 to 28/4/92 sprayed with paclobutrazol on 31-07-90 and, repeated on 06-03-91.

7.3.5.2 Vegetative flushing

There was a strong growth flush (Fig. 7.18A) (the so-called generative flush) in September and the increase was almost significant ($P \leq 0.05$) for trees treated with 500 mg l⁻¹ paclobutrazol. Some flushing occurred in July for paclobutrazol and control trees. The major difference between control and paclobutrazol-sprayed trees, i.r.o. flushing, was the greater intensity of the generative flush in September, which possibly resulted in a bigger "photosynthetic factory" for flowering and fruiting. In November and December there was a small peak in flushing, although this may have been a reaction to leaf damage during the hailstorm in October. Near the end of the harvest season (March/April) the post-harvest vegetative flush occurred.

7.3.5.3 Reproductive growth

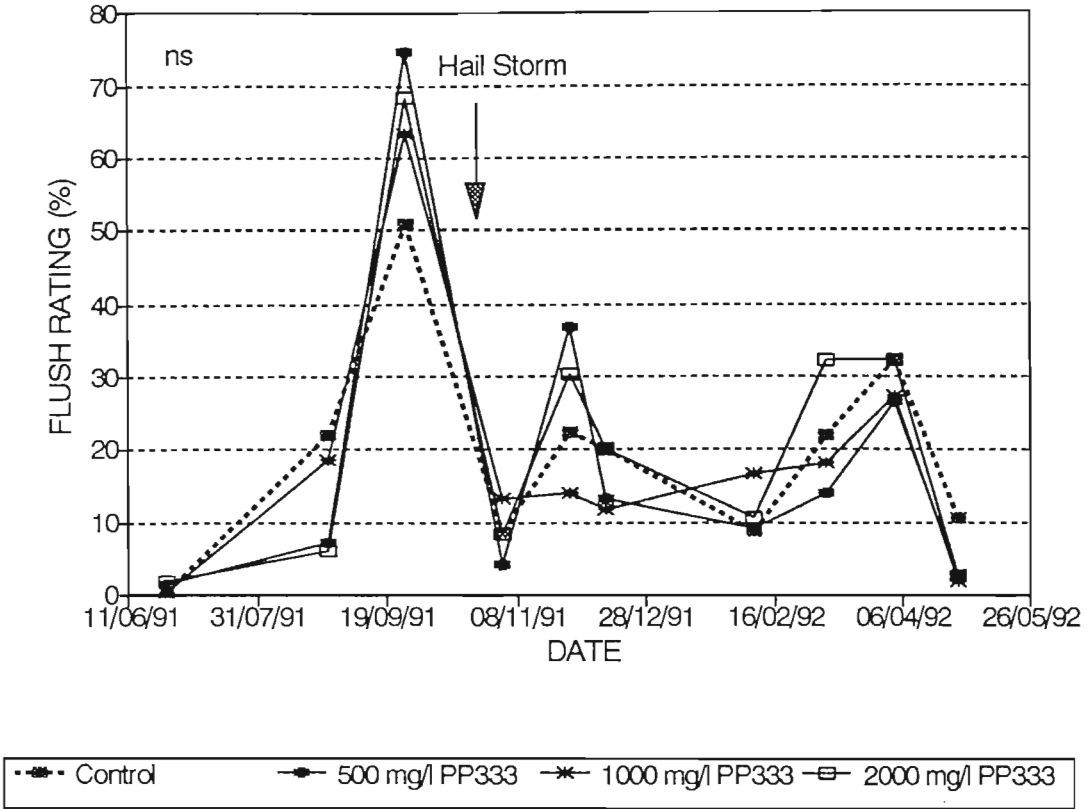
During the 1990/91 season, although the 2000 mg l⁻¹ paclobutrazol trees, had significantly higher ($P \leq 0.01$) flower ratings than the control in mid-September, control trees had more intense peak flowering than all paclobutrazol treatments (Fig. 7.19A). This was thought to be due to the sprays being applied at the wrong time, and therefore missing the target phenological event, namely the end of the post-harvest flush, after which flower induction was suspected of taking place. Therefore it was decided that the following season's application would be done near the end of the post-harvest vegetative flush, and this seemed to pay dividends.

During the 1991/92 season, paclobutrazol applications resulted in early panicle emergence (end of July) and flower bud formation (Fig. 7. 18B) when compared to controls. On 24-07-91, a highly significantly ($P \leq 0.01$) greater percentage of panicles had emerged on trees with 2000 mg l⁻¹ (12.0 %) than on controls (0.5 %). The means became significantly greater ($P \leq 0.05$) between 1000 mg l⁻¹ trees (18.2%) and controls (3.1%), and highly significant between 500 mg l⁻¹ (27.6%) and 2000 mg l⁻¹ (24.1 %) trees on the one hand, and controls on the other, by 13-09-91. At the end of September, unopened flower bud ratings for 500 mg l⁻¹ paclobutrazol trees were significantly ($P \leq 0.05$) greater than controls, and after this there was some significance, but not always predictable. This was the case until the end of October (when the hailstorm occurred).

The early panicle emergence and flower bud formation caused by paclobutrazol applications resulted in significantly higher flowering (at least at $P \leq 0.05$) by all paclobutrazol-treated trees (Fig. 7.19B), from the end of July to 19 October, when the hailstorm affected flowering. The spray programme against powdery mildew (*Oidium anacardii*) at the estate only started at the end of September due to economic reasons (the main flowering season usually only starts around the end of October, so any flowering before that is considered economically negligible to management and is sacrificed), and therefore a lot of flower buds and flowers were lost early in the flowering season. With earlier powdery mildew control the flowering and possibly yields trees could have been much higher from paclobutrazol-treated trees. During the main flowering season (Fig. 7.19B) (December to February), the peak flowering intensity was significantly higher ($P \leq 0.01$) for trees with 500 mg l⁻¹ paclobutrazol (73.0%) compared to flowering of controls (47.5%).

According to Pavithran & Ravindranathan (1974) there is usually a male flowering phase, followed by a mixed hermaphrodite and male phase, followed by a male phase. However, at Mosi Estate it was observed that about 10 % of early flowering was hermaphrodite, and this meant that considerable yield was possibly lost to powdery mildew. This early mixed phase confirms observations in east Africa where the first male phase is usually non-existent (Northwood, 1966).

(A)



(B)

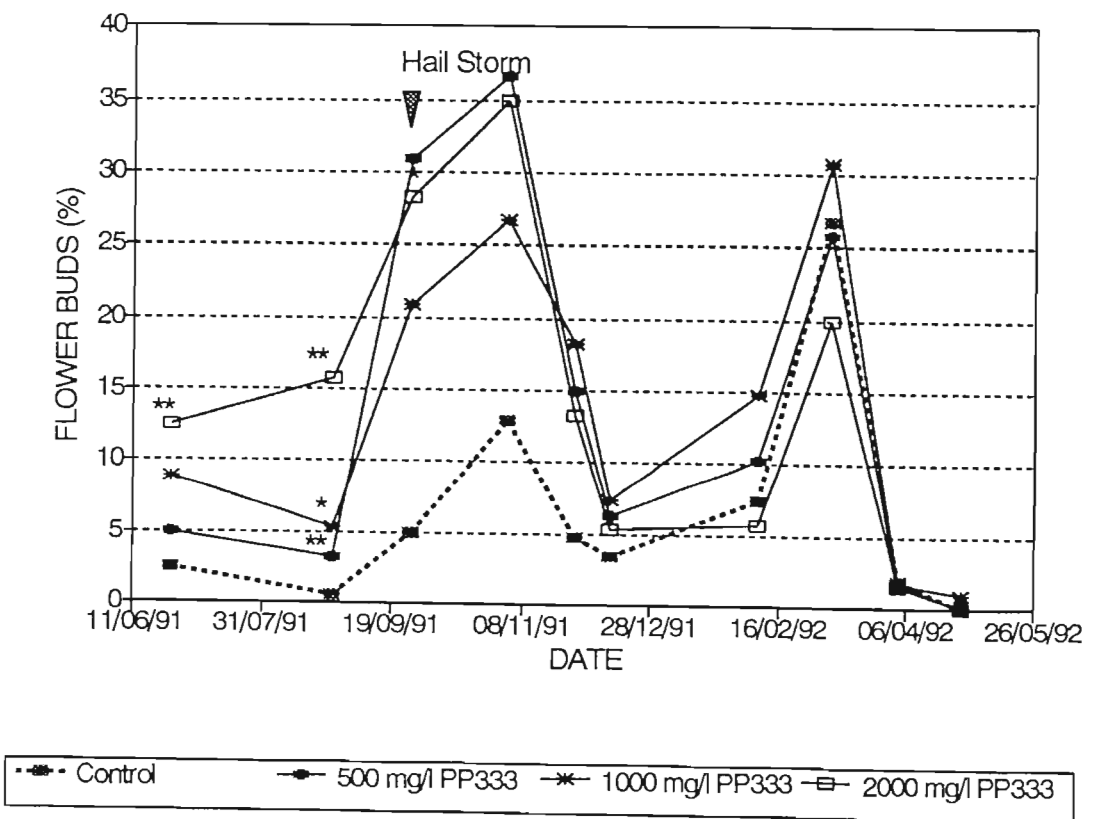


Fig. 7.18.

(A) Vegetative flushing and (B) blossom bud ratings of cashew trees sprayed with paclobutrazol. Data were square root transformed ($x' = \sqrt{x+0.5}$) for statistical analysis and means were then detransformed for presentation. (* and ** indicate significant differences from control at $P \leq 0.05$ and $P \leq 0.01$ levels respectively).

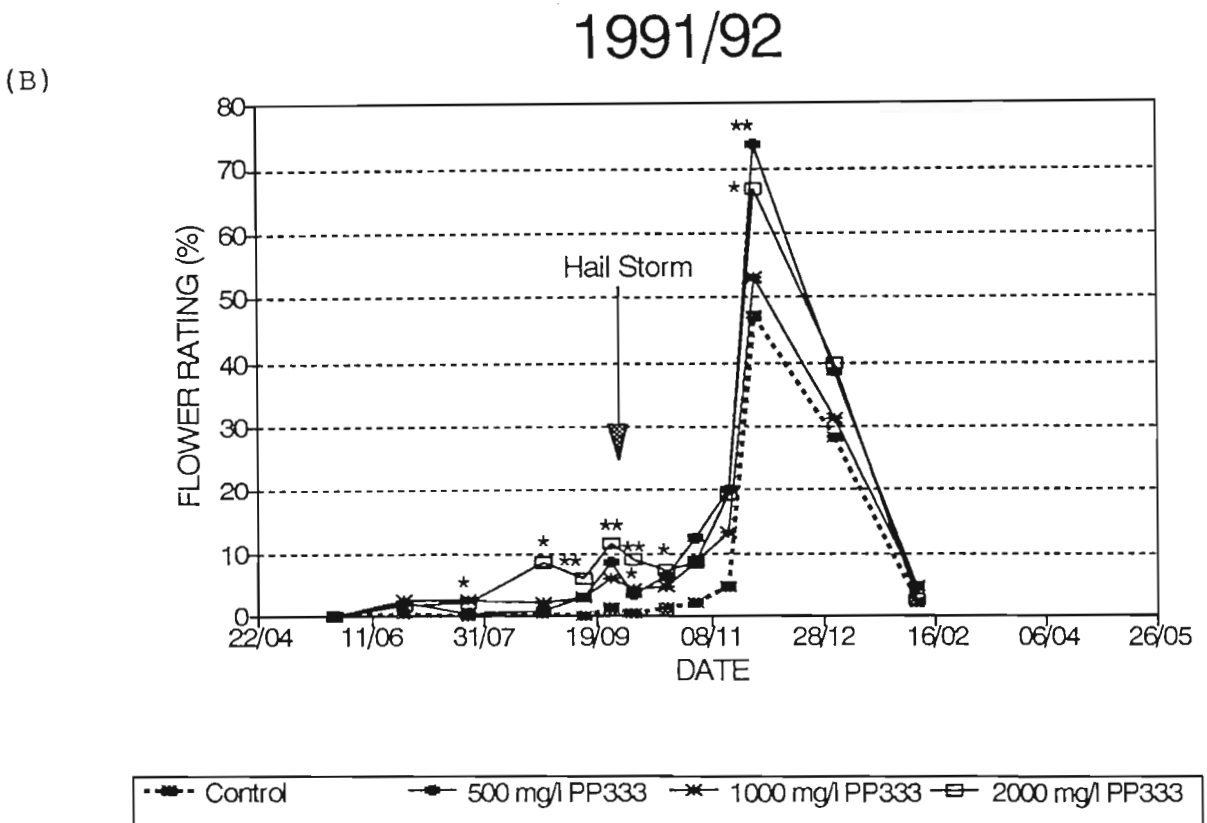
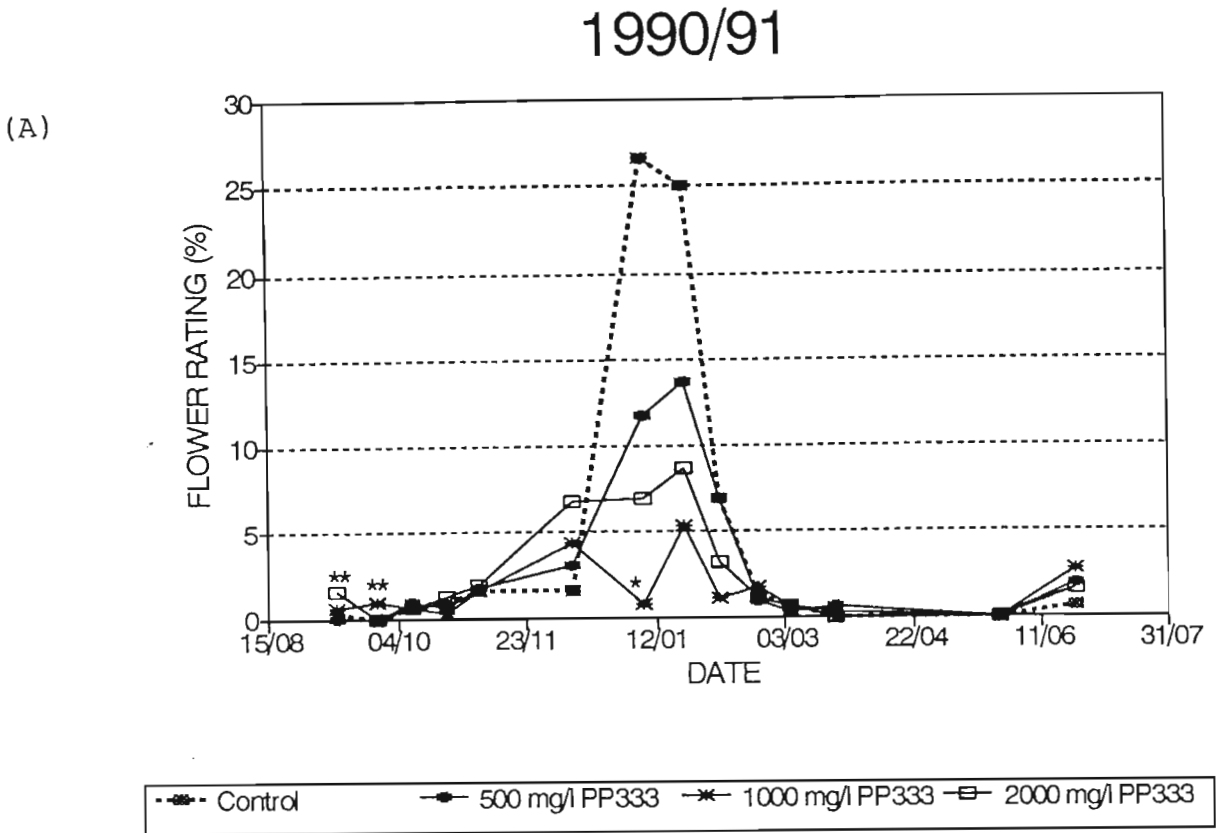


Fig. 7.19. Flower ratings for cashew trees sprayed with paclobutrazol (A) 1990/91, and (B) 1991/92. Data were square root transformed ($x' = \sqrt{x+0.5}$) for statistical analysis and means were then detransformed for presentation. (* and ** indicate significant differences from control at $P \leq 0.05$ and $P \leq 0.01$ levels respectively).

7.3.5.4 Yields

There were no significant differences between the paclobutrazol and control trees i.r.o. total yields in 1990/91 (Fig. 7.7A). During this season, compared to the control (318 g NIS tree⁻¹), 500 mg l⁻¹ and 2000 mg l⁻¹ paclobutrazol trees yielded slightly more (386 g and 452g NIS tree⁻¹ respectively), but 1000 mg l⁻¹ yielded poorly (Fig. 7.7A). In the 1991/92 season (Table 7.2; Fig.7.7B), 500 mg l⁻¹ paclobutrazol was the highest average yielder (4135.8 g NIS tree⁻¹) of all treatments in the trial, and this was significantly greater ($P \leq 0.05$) than the grand mean of all treatments. The mean yields of the other two paclobutrazol treatments were greater than both the control and grand mean total yields, although not significantly so.

Paclobutrazol had the effect of spreading the harvest into a much longer period than the control trees. There is evidence that high levels of gibberellins in mango (Pal & Ram, 1978), and citrus (Monselise & Goren, 1978) inhibit flower production. Paclobutrazol is a broad spectrum, xylem-mobile plant growth regulator (Lever, 1986). Its mode of action is the inhibition of gibberellin biosynthesis (Dalziel & Lawrence, 1984). This is the rationale behind the use of this growth regulator to improve flowering.

The reason for the relatively high cashew yields appeared to be because of the early start to flowering and fruiting, (although even during the peak harvest period, the controls were outyielded by the two highest yielding paclobutrazol treatments), a lack of a competitive vegetative flush during peak flowering, lower growth rates, allowing more energy to go into flower and fruit production, and countering the flowering-inhibitive action of gibberellins. These data confirm Kulkarni's (1988), and Tongumpai *et al.*'s (1989) results, who reported earlier, more intensive flowering, leading to significantly higher yields on paclobutrazol-treated mango trees.

7.3.5.5 Leaf Ammonia Content

Ammonia content in the leaves of paclobutrazol-sprayed cashew trees did not differ much from controls. There appeared to be a slight increase in leaf $\text{NH}_3/\text{NH}_4^+$ about two months after application (Fig. 7.20), and the general upward trend was maintained until the last leaf sample was taken in October 1991. There was a period of waterlogging from the end of May 1991 to the beginning of September 1991, and this additional stress may have resulted in the slightly higher levels when compared to control trees. Atkinson (1986) found a decrease in transpiration in apple leaves, and Asamoah & Atkinson (1985) found increased stomatal resistance of cherry leaves treated with paclobutrazol. These phenomena may have reduced the ability of the cashew trees in this trial to pump water out of the root zone, and therefore more stress than controls could have resulted from the waterlogging.

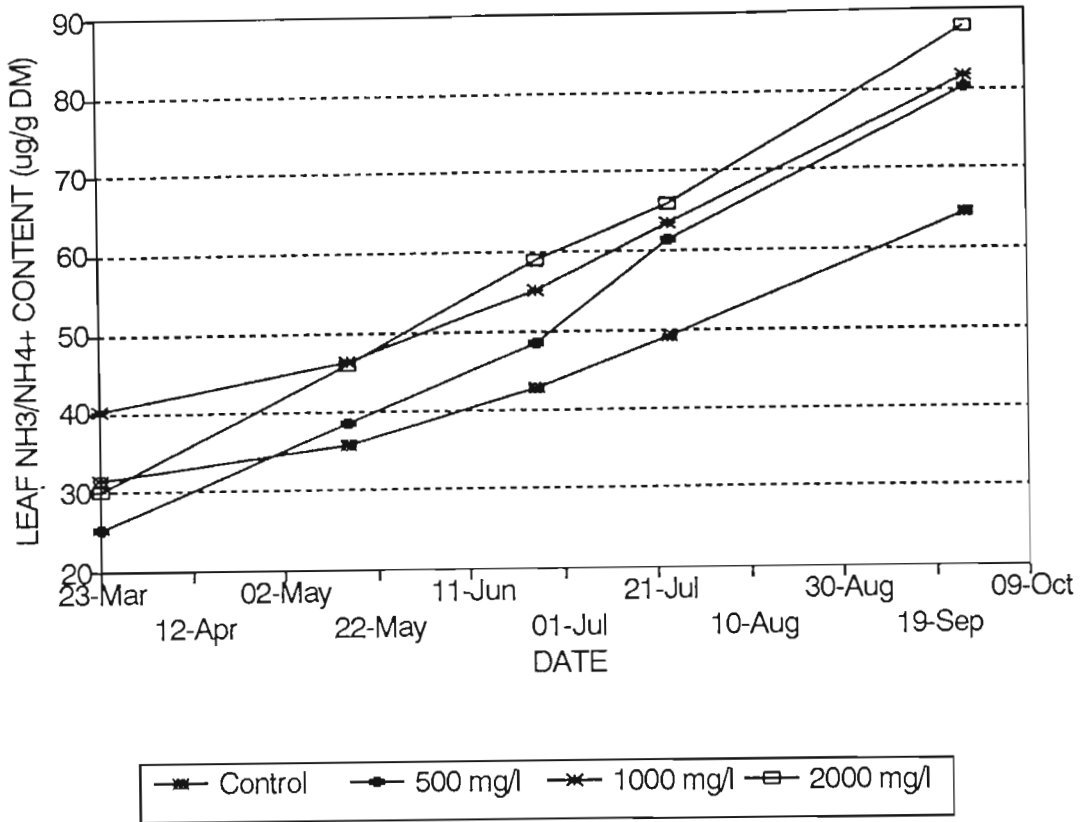


Fig. 7.20. Leaf $\text{NH}_3/\text{NH}_4^+$ levels for 1991 of trees sprayed with paclobutrazol on 27 July 1991.

7.3.5.6 Trunk Starch Content

There was no significant difference, in trunk starch content, between paclobutrazol-treated cashew trees and control trees (Table 7.3). However there was a trend for higher starch levels in the trees sprayed with 1000 and 2000 mg l^{-1} paclobutrazol. Even on the day that the trees were sprayed there were greater starch levels in these trees, indicating a possible benefit from the previous season's applications (this was the second season of trial). Steffens & Wang (1986) suggested that inhibited shoot growth led to an accumulation of stored carbohydrate in woody tissue, and this was possibly the case with cashew trees in this trial.

7.4 CONCLUSIONS

One of the basic demands of tree crop research is to draw up a phenological model for the specific area, and in this aspect, the trial was successful. Management decisions should be based on this phenological model, and it should be updated every season, as the data base becomes larger, and more sets of growing conditions are encountered. The phenological model and climatic data showed that flowering and fruiting definitely coincided with periods of wet weather, a highly undesirable situation in cashew cultivation, and hence the attempt to manipulate flowering in the first place. However, the problem of flower disease incidence, during these wet periods, has been solved quite satisfactorily by

developing an economically viable spray programme concurrently with this study. The phenological model also demonstrated a period of dormancy, brought on mainly by cool weather and not by drought stress, as most of the literature studied suggests. One aspect where the model is lacking is root growth; a study should be embarked upon to find out the timing of root flushes in Maputaland, because some management inputs (eg. application of rapidly leachable or unstable fertilizers, soil applied paclobutrazol, *Phytophthora* control measures) could be optimised by timing them to coincide with root flushing.

The chemical manipulation trial, apart from being located on a non-ideal trial site, was dogged by bad luck (fire, hail storm, flooding) and should be continued for a few more seasons for more reliable data. Ideally, it will have to be repeated using clonal trees for less variable data and more convincing results. This trial has shown that cashew flowering and yields can be manipulated chemically to a certain extent, but other factors (most notably genetics and environment) have a greater role to play in the growth and development of cashew trees in Maputaland.

Ethephon at 100 to 200 mg l⁻¹ resulted in high yields, even though flower intensity was similar or lower than control trees. This fact deserves further investigation, particularly from the flower sex ratio aspect, over longer periods of time and at different application times. Ethephon at higher concentrations (500 and 2000 mg l⁻¹) were detrimental to the cashew trees which lost almost all their leaves, leading to excessive carbohydrate utilisation and disturbed phenology to such an extent that flowering and yields were significantly depressed. For this reason these high concentrations cannot be recommended.

Potassium nitrate spraying affected vegetative growth more than it did reproductive growth, only tree height being significantly less than control trees. Only at 10 g l⁻¹ was there any yield advantage over controls. The flowering benefits noticed in some mango cultivars were not evident from this trial. Therefore KNO₃ cannot be recommended for the reproductive manipulation of cashew trees in Maputaland. It has also not been successful in induction of flowering of mangoes in the subtropics, as opposed to the lowland monsoonal tropics.

Low-biuret urea at 20 g l⁻¹ resulted in relatively high yields and earlier flowering, and this appears to be a cheap method of flower manipulation. Further studies need to be made on the timing of application and timing of flower induction in Maputaland, so that increased leaf NH₂/NH₄⁺ can coincide with, or slightly precede, flower induction, the target event.

Paclobutrazol sprays showed remarkable promise because of consistent results, which were the most convincing of the whole trial. Paclobutrazol, particularly at 500 mg l⁻¹, sprayed on the post-harvest vegetative flush appears to show promise by increasing flowering, decreasing tree growth, increasing

stored carbohydrate levels, and improving yields. However, further investigation, particularly into soil applications, needs to be carried out. Linked to this, a study of cashew apple and nut residues will have to be carried out before this product is used on a commercial scale, particularly if the products are to be exported to destinations with very strict residue standards.

This is an aspect to consider with any chemical manipulation; the emotive nature of some consumers. In mainly developed countries, the environmental lobby groups are sometimes fanatical to the point that any chemical (natural or synthetic; toxic or harmless) applied to the trees is considered a threat to the environment and consumers, regardless of scientific findings. There could be problem with the marketing of products which come from chemically manipulated trees, and therefore physical methods of tree manipulation should be considered before a chemically based programme.

Economic analysis of each treatment was not carried out, and therefore, the author cannot recommend with certainty that there will be any economic benefit from the use of any of the treatments described in this trial. The author's opinion is that since no **significant** yield advantage was obtained from any of the treatments, and because the major reason for trying to shift flowering, namely flower diseases, has been solved to satisfaction, there is no need presently to chemically treat trees as in this trial, unless a very substantial yield advantage can be shown in future trials (in the absence of climatic upsets).

CHAPTER 8: GENERAL DISCUSSION AND CONCLUSIONS

Taking the results of all the trials into consideration the major objectives of this project, namely to study the flowering ecophysiology of cashew and attempt to shift the flowering period out of the rainy season, were not able to be fulfilled completely. This was partially due to an almost complete lack of flowering in young potted seedling trees in the glasshouse trials, some bad luck in the field trials (fire which destroyed the first chemical spray trial, an untimely hailstorm and out-of season flooding at Mosi Estate, etc.), and probably most importantly, a complete lack of clonal trees for experimentation. This made data extremely variable, particularly in the field trials. Therefore statistical analysis of the data from these trials was made difficult and in some cases almost impossible. Factorial trials, using single tree plots, with such trees were quite ineffective and most interaction effects were lost due to high variation. Other problems encountered were the long distances between the University of Natal and the field trial sites (c. 500 km), and non ideal growing conditions for cashew (poorly drained soil with water table varying in depth from 0 to 200 cm below the soil surface) at Mosi Estate.

Cashew trees reacted to low temperatures and drought (both in glasshouses and in the field) in a fashion typical of trees originating in a tropical monsoonal area, the trees being able to withstand drought conditions better than low temperature conditions. At Makatini Research Station, where monthly mean minimum temperatures dropped below 15°C, and mean temperatures below 20°C for about four months, the trees were induced into flowering primarily by low temperatures. However, mean temperatures of 17°C (24°C day/9°C night) under glasshouse conditions resulted in cold damage to young plants after 8 weeks. Therefore, if cashew trees are grown in areas which receive such levels of cold, young trees should be protected for a few years, until they reach suitable hardiness. Older trees were able to withstand the winter temperatures relatively well.

Temperature was found to be the dominant factor over drought stress in the control of flower synchrony. It is probable that, when temperatures are optimal for growth, as in the lowland tropics, a pronounced drought stress period is necessary for flower induction. However, when temperatures are lower than optimum for several months, the drought stress requirement is over-ridden by the more powerful low temperature cue, as in hot subtropical Maputaland. If this is true, then one of the major factors believed to be limiting for cashew in Maputaland, the low temperatures in winter, may be more beneficial than harmful for cashew cultivation. This phenomenon was found in litchi by Menzel & Simpson (1989; 1990; 1991), but was not expected in the tropical cashew. Flowering only started once mean monthly temperatures exceeded 23 to 24°C and mean minimum temperatures were greater than 15°C in spring. Two other environmental factors which reduced the role of drought stress in flowering were unseasonal autumn and winter rains (i.e. lack of a truly monsoonal climate), and the shallow water table of the coastal sandy soils of Maputaland.

Chemical manipulation of cashews in the field showed varying results. Paclobutrazol was the most promising foliar chemical spray, earlier and more intense flowering. In the glasshouse and at Mosi Estate, urea at 2% looked promising as a means of improving flowering and yields. Ethephon sprays at low concentrations 100 to 200 mg l⁻¹ looked promising to improve flowering (possibly influencing sex ratios, rather than flower intensity) and yields. KNO₃ at 1% concentration also gave good yields. However the yield improvements (of average data) over unsprayed controls were not significantly different, and therefore cannot be recommended on the basis of these results. The early panicle production or flowering resulting from these treatments was negated by a hail storm which all but decimated these panicles. The potential flowering and yield lost due to hail storm could not be estimated, and therefore it would be desirable to repeat the treatments for another season at least. Soil applied paclobutrazol should also be tested, and residues in the soil and nuts monitored. An aspect to keep in mind is the acceptability of agricultural products treated with "chemicals", particularly the "hormones" which are especially emotive. If the products are to be exported to developed countries with a strong environmental lobbyist group, then it may be wise to refrain from using chemical manipulation means, and to attempt physical tree manipulation.

Trunk girdling was not successful as a tree manipulation technique. Girdled trees grew, flowered and yielded poorly compared to ungirdled trees. The girdling of cashew trees growing under marginal conditions cannot be recommended and is not desirable. Only trees growing optimally and very vigorously should be girdled, to decrease vigour and attempt to induce reproductive growth on vegetative trees. This was clearly not the state of the trees in Maputaland, and the cool temperatures were sufficient to curb excessive vegetativeness. Branch rather than trunk girdling was not attempted.

The yields of some four-year old cashew trees in Maputaland were surprisingly high. Mean yields of 25 trees at Makatini Research Station exceeded 4 kg tree⁻¹, and some individual trees yielded well over 10 kg NIS. On a per hectare basis a mean yield of 4 kg tree⁻¹ planted at 8 x 5 m (250 trees ha⁻¹) is equivalent to 1 t ha⁻¹, exceeding the world average reported by Chacko *et al.* (1990). This is an encouraging sign as future yields will exceed these levels. In Australia, with high labour and other costs, economic analysis indicated that to be economically competitive, yields of 4 to 4.5 t ha⁻¹ under irrigation and at high plant density would have to be achieved. In Maputaland where irrigation is not envisaged, a relatively good profit could be made at 2 or more t ha⁻¹ (Staples¹, pers. comm., 1992). From the yields achieved in this project from such young trees, these yields may not be as difficult to achieve as was originally thought, provided that some form of seedling selection is carried out locally, and good management techniques applied (especially the control of blossom diseases).

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The leaf $\text{NH}_3/\text{NH}_4^+$ of cashew trees in the field and in the glasshouse increased under almost all stress conditions. The more severe the stress, the higher the leaf $\text{NH}_3/\text{NH}_4^+$ content. The increased leaf $\text{NH}_3/\text{NH}_4^+$ levels, in many cases, were accompanied by decreased starch levels. The results are in agreement with Rabe's (1990) hypothesis, viz. that any stress causing a decrease in glucose levels and/or growth, or impaired plant health will result in $\text{NH}_3/\text{NH}_4^+$ accumulation early in the stress period. The starch levels presumably decreased due to mobilisation of stored starch to supply energy for the *de novo* arginine biosynthetic pathway, which detoxifies the leaf by using up free $\text{NH}_3/\text{NH}_4^+$ (Rabe, 1990), and is energy expensive and requires C for the carbon skeletons necessary for N-containing compounds. What are the practical implications of this? It indicates that there is a certain level of stress needed as a flowering stimulus, which may come from almost any stress factor (temperature, drought, waterlogging, disease, *inter alia*). However there is a fine line which divides desirable levels of stress from damaging levels, and this line remains to be determined. Too much stress would result in decreased carbohydrate levels, which equates to decreased production potential. It is expected that only once carbohydrates produced by current photosynthesis cannot cope with the energy demands, will starch be mobilised from storage. Photosynthetic studies in conjunction with further nitrogen and starch analyses, will go a long way towards understanding this aspect more fully.

The Makatini Flats was rated as an area for future cashew production by Roe (1992) according to Mahapatra & Bhujans' (1974) land selection criteria. The area was found to be marginal for commercial cashew cultivation mainly because of low winter temperatures and rainfall which coincides with flowering. However, the cashew tree population in Maputaland is genetically extremely diverse, and although this was listed a problem for horticultural experimentation, the likelihood that trees adapted to these marginal conditions could be found within these populations, is great. One of the major problems at the start of the trial was flowering diseases, viz. powdery mildew (*Oidium anacardii*) and anthracnose (*Colletotrichum gloeosporioides*) brought about partly by wet conditions during flowering. Research done concurrently with our project has shown that these diseases can be controlled economically, and they are no longer major limiting factors. Cool temperatures were shown in this project to be quite beneficial for flower synchrony, in effect replacing the need for prolonged drought stress. Therefore, although not an ideal location, the commercial production of cashews in selected sites in Maputaland (sandy soils with water table 1.5 to 5 m deep) is possible and, if developed correctly, should be profitable, particularly to the rural communities living in areas where the soil fertility is low. The role of the fluctuating water table, and selection of sites with a suitable (as yet unknown) depth to average water table, are deserving of further study. Similarly, the role of the well developed lactifers and latex in the maintenance of turgor is an interesting academic as well as practical problem.

A problem worthy of further study is the very prolonged flowering period (7 to 8 months). This suggests that the winter cold was insufficient to strongly synchronise flowering in late winter or spring - perhaps

because any attempt to induce drought stress was partly negated by either untimely rain, or more likely by sinker root access to a relatively high water table. It is possible that on deeper soils (water table depth at least 5 m), drought stress could be used to reinforce cold stress, with a resultant more synchronised flowering. It must also be borne in mind that flowering in mid summer and autumn could not have been induced by winter cold 6 to 9 months earlier. The maputaland climate and high soil water table may therefore disrupt tree physiology and phenology to a greater extent than would probably be the case in an area with similar heat unit accumulation, but with a more pronounced dry season and a deeper water table.

Regarding the basic understanding of cashew a number of studies still need to be undertaken. The effects of root temperatures on flowering and growth of cashews need to be determined. This factor has been found to influence the earliness of root activity after winter in citrus (Monselise, 1947) and litchi (Menzel & Simpson, 1990), and possibly the earliness of flowering. Selection and breeding need to be continued, and stepped up if possible, so that high yielding clones better suited to Maputaland conditions can be found. The potential market in this country alone is vast and the otherwise relatively barren parts of Maputaland with sandy soils can be planted to cashew trees which can earn this depressed rural region valuable income, as well as providing jobs at relatively low cost. The scale of any such commercial project would be sufficiently small, and unlikely to be ecologically disruptive in an area which is ecologically vulnerable, of low agricultural potential, and probably best suited to conservation and eco-tourism. It could in fact be argued that uncoordinated peasant agriculture and a burgeoning population will, in the absence of suitable development schemes, be far more ecologically disruptive.

In conclusion, the results of this project were obtained on variable trees under difficult circumstances, and this should be borne in mind. Many of the explanations in this thesis have been of a speculative nature and could be proved wrong with further research, which is encouraged. A lot of research is still required, particularly since Maputaland possesses a unique environment which is considered marginal for cashew cultivation. So far, though there is nothing to suggest that cashew cannot be grown successfully on a commercial scale in this area, with careful consideration of microclimate and adequate plantation management. Indications are that soils with an average depth to water table of at least 3 m should be chosen, which may however necessitate supplementary irrigation for acceptable yields. In a relatively low-yielding crop, traditionally grown with low management inputs, economic viability could be compromised by such intensification, unless selection of higher yielding seedling lines or preferably clones is first undertaken.

SUMMARY

There is interest in developing a cashew industry in Maputaland, the far north-eastern corner of Natal/KwaZulu. As part of a feasibility study, this project was embarked on to determine whether cashew flowering could be manipulated in any way. Flowering and fruit development coincided with a rainy period, with accompanying serious flower diseases (*Oidium anacardii* and *Colletotrichum gloeosporioides*). The project consisted of glasshouse studies at the University of Natal, Pietermaritzburg, to determine the effects of low temperature, drought stress and urea sprays on cashew flowering under controlled conditions, as well as field studies in Maputaland to determine the effects of chemical sprays and the timing of a winter water deficit period on cashew growth, flowering and yields. The project ran for two years and was then terminated.

Young (18 months at commencement) seedling plants growing in 20 l pots were used in glasshouse studies. In order to determine the effects of low temperature and duration of drought stress, a factorial design with treatments 0, 3, 6 and 9 weeks of low temperatures (24°C day/ 9°C nights)(factor A) and 0, 3, 6 and 9 weeks of water deficit (Factor B) was used, with both factors in all combinations. During the second season the durations were increased to 0, 4, 8 and 12 weeks for both factors. There was no flowering and the major objective of studying flowering was not achieved. Tree growth was not affected significantly by drought and/or cold duration. Mean dawn stomatal conductance was $304.1 \pm 46.8 \text{ mmol m}^{-2} \text{ s}^{-1}$. Temperature appeared to be the dominant stomatal controlling factor at low temperatures, stomatal conductance and transpiration being suppressed by cold regardless of soil water potential. At more optimum temperatures for growth, stomatal conductance was dependent on soil water potential ($r^2 = 0.756$). Cashew trees were able to recover from drought within one week, but up to one month was required for recovery from cold stress. Starch levels in the roots, dry matter production in the leaves, roots and stems, as well as leaf area were decreased significantly ($P \leq 0.01$) with increasing low temperature duration. It was concluded that no long term damage was done to the plants, but cashew, particularly young trees should not receive cold stress at the temperature regime used for longer than 8 weeks. The leaf anatomy and thickness of glasshouse-grown trees differed from field grown trees and therefore these results may be slightly different in the field.

A study of the effects of foliar urea at concentrations of 0, 1, 2, 4 and 8 g urea 100 l⁻¹ applied once, twice or thrice at fortnightly intervals was undertaken under glasshouse conditions. The treatments were applied in late autumn/ early winter of 1990 and 1991. Tree growth and flowering were monitored, and starch and leaf $\text{NH}_3/\text{NH}_4^+$ analyses carried out. The highest urea concentration (8%) resulted in leaf scorch and abscission, extremely low stem diameter growth rates, and was too high for glasshouse trees. The starch contents of the 8% urea treatment were depleted significantly ($P \leq 0.01$) more than the other concentrations, most probably due to the energy demand by the plants' ammonia

detoxification mechanisms. The 1%, 2% and 4% urea treatments resulted in vigorous growth and high dry matter production. There were no significant effects of the number of sprays on cashew growth. Only seven trees flowered, and therefore no definite conclusions could be drawn regarding urea effects on flowering. Most hermaphrodite flowers (max. 76.8% hermaphrodite) opened soon after first anthesis of a panicle, and all terminal flowers of panicle branches were hermaphrodite. Flowers generally opened basipetally in a panicle, starting with hermaphrodite flowers and with progressively more male flowers. Urea sprays resulted in $\text{NH}_3/\text{NH}_4^+$ build-up in the leaves. Treatments that flowered (1, 2 and 4% urea) had $\text{NH}_3/\text{NH}_4^+$ levels ranging from 100 to 700 $\mu\text{g g}^{-1}$ DM for approximately a month. Control trees had $\text{NH}_3/\text{NH}_4^+$ levels of c. 50 $\mu\text{g g}^{-1}$, and trees sprayed with 8% urea resulted in phytotoxic $\text{NH}_3/\text{NH}_4^+$ levels above 1200 $\mu\text{g g}^{-1}$ DM.

A field trial was carried out at Makatini Research Station to determine the effects of timing of a two month winter drought period on flowering and growth. An observational trial to determine the effects of girdling on growth and flowering was incorporated in the border rows of the irrigation trial. The trial tested five treatments (no irrigation during: May and June, June and July, July and August, August and September, and a control treatment which received irrigation throughout winter). Mean monthly temperatures were below 20°C, and mean minimum temperatures below 15°C for the 5 winter months during treatment application. There were no significant differences in tree growth, flowering, flushing, or yields between drought stressed treatments and control. Trees receiving no drought stress flowered and bore fruit not significantly differently from those receiving drought, which indicated that cold could indeed replace the requirement for drought to induce flowering, and that, under the conditions at Makatini, autumn and winter temperature was the overriding factor controlling initial flower induction. Flowering occurred from early October (when mean temperatures exceeded 23 to 24 °C) to late April (7 months - a prolonged flowering period), when mean monthly temperatures dropped below 23 to 24°C. Girdling of cashew trees in March and May, using girdle widths of 1, 5 and 10 mm were not successful in improving flowering and yields under the conditions of the trial. The stress induced by the wider girdles was appeared to be too intense for cashew trees growing in sub-optimum conditions.

A trial to test the effects of chemicals on four-year old cashew trees was undertaken at Mosi Estate in Maputaland. The chemicals tested were foliar applied ethephon (50, 100, 200, 500, 2000 mg l^{-1}), KNO_3 (1%, 2%, 4%), urea (1%, 2%, 4%) and paclobutrazol (500, 1000, 2000 mg l^{-1}). A phenological model based on the phenological data of 203 trees used in trials in Maputaland was drawn up for cashew. There was a dormant period during winter, followed by a generative flush. From this flush panicles were produced (peak November/December), and flowering peaked in early January. The harvest period peaked in February and March. There was a strong post-harvest flush before entering the dormant period. Trunk starch levels were at their highest after the dormant winter period, and at their lowest following the harvest. Ethephon at high concentrations (500 and 2000 mg l^{-1}) resulted in excessive leaf

drop, disturbed the root:shoot balance and normal phenological patterns, and gave poor yields. The best ethephon concentration was 100 to 200 mg l⁻¹ which gave average yields higher than controls (not significant). KNO₃ had no effect on tree growth, flushing, flowering or yields when compared to control trees. Urea at 2% concentration gave a significant increase ($P \leq 0.05$) in flushing and simultaneous decrease in flowering following a hail storm in October 1991. Paclobutrazol at 500 to 2000 mg l⁻¹ resulted in significantly lower growth rates, and early panicle production. This early reproductive growth was destroyed by a hail storm, and therefore could not be converted to yields. Even so, the mean yields of all paclobutrazol treated treatments were higher than controls. From results of this trial, the use of these chemicals to improve yields and manipulate flowering may not be economically justified, and the emotive nature of tree manipulation by chemical methods, implies that other, non-chemical methods of manipulation should rather be attempted. The most promising chemical for further research was paclobutrazol.

There is no reason to suggest that a commercial cashew venture in Maputaland will not succeed, with careful choice of the right sites, and adequate management. Blossom diseases appear to be controllable, and the cool winter temperatures are not as harmful as originally thought and may even be beneficial for flowering under conditions of unpredictable rainfall distribution and high water tables in sandy soils. Success or failure will depend on the adaptability of the planting material used, and the necessity for and cost of additional management inputs.

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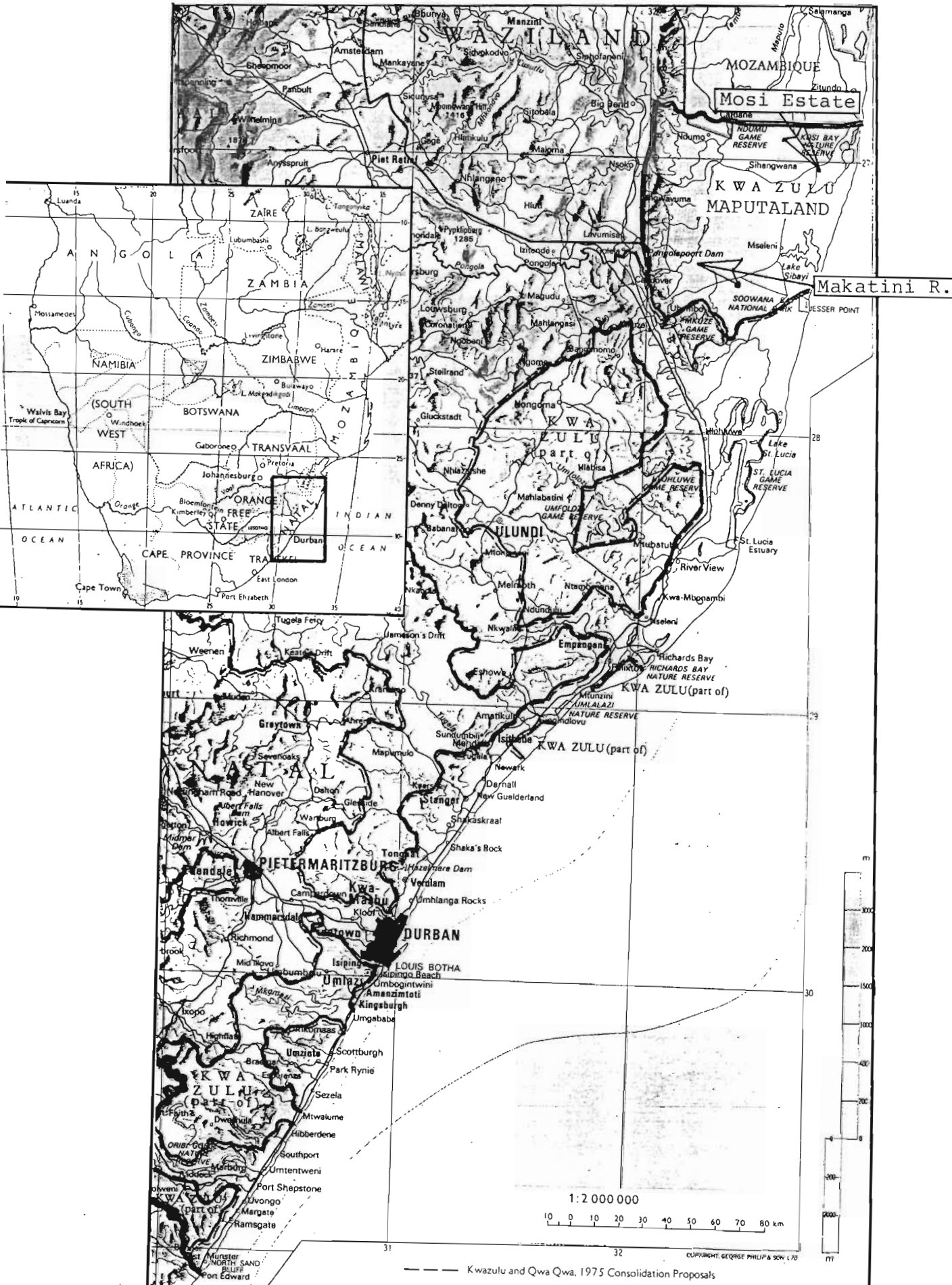
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APPENDIX I. MAP OF NATAL INDICATING POSITION OF TRIAL SITES IN MAPUTALAND



APPENDIX II. GUIDELINES FOR THE SELECTION OF LAND FOR CASHEW IN INDIA (Mahapatra & Bhujan, 1974).

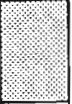


	VERY GOOD (CLASS I)	GOOD (CLASS II)	FAIR (CLASS III)	POOR (CLASS IV)	UNSUITABLE (CLASS V)
<i>1. Soil Characteristics</i>					
1.1 Soil depth (m)	1.5	0.9 - 1	0.45 - 0.90	0.23 - 0.45	<0.23
1.2 Texture	Loam Sandy loam	Loamy sand Silty loam Coastal sand	Clay loam Sandy clay loam Silty clay loam Loamy skeletal	Gravelly clay loam Gravelly silty loam Gravelly sandy loam	Gravelly clay Sandy clay Silty clay Clay
1.3 Reaction	Slightly acidic to neutral (pH 6.3-7.3)	Slightly acidic (pH 6.0-6.3)	Medium acidic (pH 5.6-5.9)	Strongly acidic (pH 5.1-5.5), Mildly alkaline (pH 7.4-7.8)	Very acidic (pH < 5.0) or very alkaline (pH >7.8)
<i>2. Land Features</i>					
2.1 Slope (%)	<3	3 - 5	5 - 15	15 - 25	>25
2.2 Watertable (m)	2 - 5	1.5 - 2.0	8 - 10	10 - 13	>13
2.3 Erosion condition	None to slight (e_0)	Slight sheet erosion (e_1)	Moderate (e_2) (Rill & sheet erosion)	Severe (e_3) (Gully erosion)	Very severe (e_4) (Gully & ravine erosion)
2.4 Drainage	Well drained	Well/ excessively drained Alluvial plain, natural levees, upland plains, coastal ridges	Moderately well drained.	Excessive drainage Imperfect drainage.	Poorly drained
2.5 Physiography	Coastal plain, delta reaches, inland laterite coastal hinterland.		Plateaux, hills, domes mounds	Denuded hill slopes with shallow soils, ridges, steeply undulating terrain with severe erosion.	Swamps Valley bottoms Escarpments Steeply sloping mountain creek plain
<i>3. Climate and environmental factors</i>					
3.1 Altitude (m)	>20	20 - 120	120 - 450	450 - 750	>750
3.2 Rainfall (cm yr ⁻¹)	150 - 250	130 - 150	110 - 130	90 - 110	>250
3.3 Dist. from sea (km)	50	50 - 100	110 - 150	150 - 200	>200
3.4 Temperature					
3.4.1 Max. summer (°C)	32.2 - 37.7	37.7 - 39.3	39.4 - 41.1	41.1 - 43.3	>43.3
3.4.2 Min. winter (°C)	15.5	13 - 15.5	11.6 - 13.3	8.8 - 11.1	<8.8
3.5 Humidity (%)	70 - 80	65 - 70	60 - 65	50 - 60	<50 or >80
3.6 Frost occurrence	None (once in 20 yrs)	None (once in 15 yrs)	Very rare (once in 10 yrs)	Occasional (once in 5 yrs)	Very often (every year)



APPENDIX III. CROP ENVIRONMENT MATRIX FOR CASHEW (Adapted from Hacket, 1990).

FACTORS	LIMITATIONS			
	Nil (LR 0-2)	Low (LR 3-4)	Moderate (LR 5-6)	High (LR 7-9)
Factors recorded as time constant				
Base Saturation (%)	>60	20 - 60	<20	....
CEC (meq 100g ⁻¹)	>25	10 - 25	<10	....
Depth (cm)	>100	50 - 100	25 - 50	<25
Drainage/ soil aeration	Well	-	Imperfect	< imperfect
Nitrogen (%)	>0.04	0.02 - 0.04	0.01 - 0.02	<0.01
pH - acidity	5.0 - 6.5	4.2 - 4.9	3.5 - 4.1	<3.5
pH - alkalinity	-	6.6 - 7.2	7.3 - 7.9	<7.9
Phosphorus (ppm)	>10	6 - 9	3 - 5	<3
Potassium (meq 100g ⁻¹)	>0.4	0.15 - 0.3	0.08 - 0.15	<0.08
Salinity (mS cm ⁻¹)	<5	5 - 8	9 - 12	>12
Slope (°)	<10	10 - 18	19 - 25	>25
Stoniness (%)	<9	9 - 5	16 - 25	>25
Texture	Medium, coarse, peats	Fine, gravel	Rocky	Swelling clays, very fine
Factors recorded as time-varying				
<u>Considered over the whole period:</u> Solar radiation, average (MJ m ⁻² day ⁻¹)	>20	9 - 20	4 - 8	<4
Temp (°C) of:				
- abs min	>9.5	8.6 - 9.5	7.6 - 8.5	<7.6
- lowest av. mthly min.	>11.5	10.6 - 11.5	9.6 - 10.5	<9.6
- highest av. mthly max.	....	....	....	....
- soil, highest av. mthly mean	....	....	....	....
- av. wkly DU's.	41 - 70	11 - 25	11 - 25	<11
Water deficit, driest month (AET/PET %)	>36	24 - 36	10 - 23	<10
Water deficit, av. overall (AET/PET %)	>36	24 - 36	10 - 23	<10
SUITABILITY (Furthest r/h column marked)	High	Moderate	Low	Nil

Rate each parameter according to the limiting rate (LR), then read off suitability for commercial cashew production as the furthest right hand column marked.

APPENDIX IV. SOIL PROFILES AND PROPERTIES OF FIELD TRIAL SITES: (A) MOSI ESTATE, AND (B) MAKATINI RESEARCH STATION.

(A)	Thickness range (cm)	Diagnostic horizons	Description
	10-50	Organic O	Black, fine to medium sand with abundant organic matter
	5-20	Gleyed B	Greyish yellow, fine to medium, mottled sand with occasional Fe-concretions.
	>200	Regic Sand	Grey, greenish grey, white, medium to fine grained sand.

(B)	Thickness range (cm)	Diagnostic horizons	Description
	10-30	Orthic A	Black, fine to medium sand with low organic matter.
	>200	Regic Sand	Grey, greenish grey, white, medium to fine grained sand.

SOIL PROPERTY	CHAMPAGNE FORM	FERNWOOD FORM (MAKATINI RES. STA.)	
	MPOSA SERIES (MOSI ESTATE)	WARRINGTON SERIES	FERNWOOD SERIES
CLAY CONTENT (%)			
Topsoil	<10	<6	<6
Subsoil	<10	<6	<6
ORGANIC CARBON (%)			
Topsoil	>10	>2	<2
APPROX. PLANT AVAILABLE WATER (mm m ⁻¹)			
Topsoil	110	100	60
Subsoil	60	30	30
APPROX. FIELD WATER CAPACITY (mm m ⁻¹)			
Topsoil	150	150	100
Subsoil	100	70	70
EROSION HAZARD			
Water	Low/ Moderate	Low/ Moderate	Low/ Moderate
Wind	High	Very High	Very High
INFILTRATION RATE (cm/hr)	4-6	10-25	32-71
EXPANSION POTENTIAL	None	None	None
SOIL STABILITY	Low	Low	Low
GENERAL FERTILITY	Low	Very low	Very low
pH CLASS	Strongly acid	Strongly acid	Strongly acid
POSSIBLE MICRONUTRIENT DEFICIENCY	High	High	High

APPENDIX V. EXPERIMENTAL LAYOUT FOR TEMPERATURE x DROUGHT STRESS GLASSHOUSE TRIAL.

WINDOWS (NORTH)

REP	132	342	222	312	112	322	442	412
2	232	432	122	422	242	212	142	332
REP	344	324	434	144	314	114	334	244
4	234	414	214	134	424	124	224	444
REP	243	423	213	333	233	113	133	343
3	123	313	413	143	323	223	443	433
REP	441	411	211	311	121	111	141	421
1	231	431	131	221	241	331	341	321
REP	345	335	225	235	215	245	415	325
5	315	125	115	145	445	135	435	425

AIR CONDITIONERS (SOUTH)

Treatments

Four durations of cold (22/10°C); **the first figure on each pot:**

- 1=Control
- 2=Four weeks
- 3=Eight weeks
- 4=Twelve weeks.

Four durations of drought stress, measured by tensiometer to c. 80 kPa soil matric potential; **the second figure on each pot:**

- 1=Control
- 2=Four weeks
- 3=Eight weeks
- 4=Twelve weeks.

Replicates

5 reps; **the third figure on each pot.**

- NOTE**
- i) From the time of stress commencement, the pots with the next highest first figure were transferred to the cool glasshouse every 4 weeks (eg. the next treatment to be transferred will be the pots starting with the figure 3, ie those getting 8 weeks of temperature stress).
 - iv) Every 4 weeks the irrigation tubes were removed from the pots with the next highest second figure.

APPENDIX VI. EXPERIMENTAL LAYOUT OF UREA SPRAY CONCENTRATION x SPRAY REPETITIONS GLASSHOUSE TRIAL

S O U T H	211	02	334	226	325	333	W
	321	412	214	326	215	323	I
	01	212	04	136	125	233	N
	131	312	434	236	225	313	D
	331	432	134	116	435	223	O
	221	112	314	416	315	213	W
	421	322	224	06	235	133	S
	111	422	414	216	115	03	
	431	122	424	436	135	413	N
	231	222	124	126	425	123	O
	121	232	114	336	335	433	R
	411	132	324	426	05	113	T
311	332	234	316	415	423	H	

Treatments

Five concentrations of low-biuret urea; **the first figure on each pot:**

0 = Control (No spray)

1 = 1 %

2 = 2 %

3 = 4 %

4 = 8 %.

Three repetitions at fortnightly intervals; **the second figure on each pot:**

1= One spray

2= Two sprays

3= Three sprays

Replications

6 reps; **the last figure on each pot.**

APPENDIX VII: EXPERIMENTAL LAYOUT FOR IRRIGATION DEFICIT TIMING, AND GIRDLE TIMING X WIDTH FIELD TRIALS AT MAKATINI RESEARCH STATION.

ROW	West						A
	G	F	E	D	C	B	
1	13	23	21	12	22	11	
2	12	22	13	11	23	21	
3				T1			
4				T3			
5				T4			
6	12	0		T2			
7				T5			
8	23	0		T2			
9				T4			
10				T3			
11				T5			
12				T1			
13				T3			
14	21	0		T2			
15				T5			
16				T1			
17				T4			
18				T4			
19				T5			
20				T1			
21				T3			
22	22	0		T2			
23				T5			
24				T1			
25	13	0		T2			11
26				T4			
27				T3			
28	22	11	23	21	12		13
29	23	13	12	22	21		11

East

KEY
Irrigation deficit timing trial

Block boundaries

Number	Treatment description
T1	No irrigation during May and June.
T2	No irrigation during June and July.
T3	No irrigation during July and August.
T4	No irrigation during August and September.
T5	Control (No drought stress).

Number	Time of girdling X girdle width trial Treatment description
0	Control (No girdle)
11	Girdle March; knife cut
12	Girdle March; 4-5 mm wide
13	Girdle March; 8-10 mm wide
21	Girdle May; knife cut
22	Girdle May; 4-5 mm wide
23	Girdle May; 8-10 mm wide

APPENDIX VIII: EXPERIMENTAL LAYOUT FOR CHEMICAL SPRAY FIELD TRIAL AT MOSI ESTATE

ROW NO	North						
	C	F	J	M	P	S	V
17		3					
16		5					
15		12		4		4	
14	7	2		9		8	
13	13	11	1	5		9	
12	6	4	8	13	5	10	9
11	11	1	12	3	11	6	2
10	10	9	4	12	1	12	13
9	3	13	10	6	4	3	5
8	4	10	3	2	11	8	6
7	9	8	7	13	6	2	12
6	5		9	11	8	13	3
5	1		7	5	2	7	11
4	2		8		10		7
3	12		6		7		1
2					1		10

South

KEY

Treatments

No.	Name	Description
1.	Control	No spray
2.	Ethephon 100 mg l ⁻¹	0.12 ml Ethrel per litre water sprayed 4 times (weekly) in May/June.
3.	Ethephon 500 mg l ⁻¹	1.04 ml Ethrel per litre water.
4.	Ethephon 2000 mg l ⁻¹	4.17 ml Ethrel per litre water.
5.	KNO ₃ 1 g 100ml ⁻¹	10 g per litre water spray when buds are swollen (late winter/spring).
6.	KNO ₃ 2 g 100ml ⁻¹	20 g per litre water.
7.	KNO ₃ 4 g 100ml ⁻¹	40 g per litre water.
8.	Urea 1 g 100ml ⁻¹	10 g low-biuret urea per litre water spray after some winter stress (May/June).
9.	Urea 2 g 100ml ⁻¹	20 g low-biuret urea per litre water.
10.	Urea 4 g 100ml ⁻¹	40 g Low-biuret urea per litre water.
11.	PP333 500 mg l ⁻¹	2.0 ml Cultar ^R per litre water spray in early autumn (Mar).
12.	PP333 1000 mg l ⁻¹	4.0 ml Cultar per litre water.
13.	PP333 2000 mg l ⁻¹	8.0 ml Cultar per litre water.

- NOTE
1. Alternate reps are shaded.
 2. The trial will was laid out using trees in an established fertiliser trial. All the trees being used received fertiliser at rate 3 (high fertiliser regime).
 3. Double lines indicate rep boundaries.