Curtin University of Technology
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School of Environmental Biology

Grasstrees as bioindicators of the present and historical chemical environment

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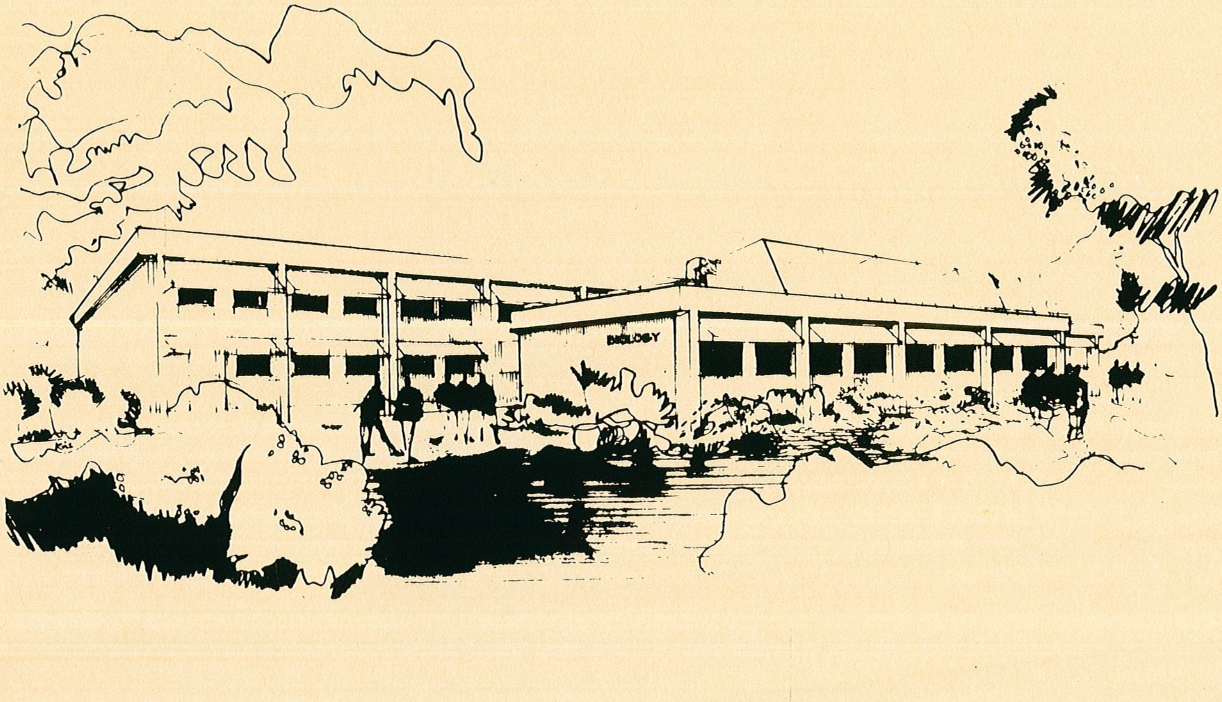

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Grasstrees as bioindicators of the present and historical chemical environment

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Xanthorrhoea preissii

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This dissertation is submitted in partial fulfilment of the requirements for the degree of Honours in the Bachelor of Science (Biology) at Curtin University of Technology. It represents 85% of the formal course requirements for one academic year.

ABSTRACT

A new technique for ageing grasstrees and determining their fire history was examined in this study. It was concluded that paired light and dark brown coloured bands along the length of *Xanthorrhoea preissii* Endl. stems were consistent with annual growth cycles, and that additional black bands were formed during the passage of fire. The coloured bands were composed of closely packed persistent leaf bases. By assessing the number of pairs of light and dark browns bands, and the frequency of black bands, it was possible to calculate the frequency of fire during the last 100 years. An overall decrease in the frequency of fire was revealed over this period. Fire frequencies in the 1890's and 1900's ranged from 3 to 4 fires per decade, this decreased to 0 to 1 per decade in the 1970's and 1980's.

The nutrient composition of leaf bases within each successive colour band along three *X. preissii* stems was analysed in an attempt to reveal long-term patterns of nutrient cycling. The innermost and outermost cm sections of the remnant leaf bases were analysed separately and usually showed different patterns, the innermost highlighting fire effects and the outermost seasonal effects. The leaf base concentrations of S, K, B, Mn, Zn and N trended downwards with the passage of time, while Ca remained relatively static. Statistical analyses confirmed significant, but temporary, increases in tissue concentrations of Ca, Mn and Zn after fire. The leaf base concentrations of Mg decreased temporarily in response to fire. Significant winter/spring peaks in the leaf base concentrations of Ca, Mg and Mn were revealed. A significant summer/autumn peak in S concentrations was recorded. No consistent pattern of variation was displayed for the concentrations of Fe and Cu within the remnant leaf bases. The concentrations of P and Na did not consistently fluctuate above trace levels. It was concluded that the distribution of certain nutrients may be used to identify and confirm the existence of annual growth fluctuations and fire events, and to reveal nutrient cycling patterns over an extended time period.

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1. GENERAL INTRODUCTION

Grasstrees are a common element in many southern Australian landscapes. The most prominent species throughout the Southwest Botanical Province is *Xanthorrhoea preissii* Endl. (the common blackboy or balga). Ward (1997) noted that different coloured bands along the length of grasstree leaf bases appeared to correspond to annual growth increments and the occurrence of fire. Lamont and Downes (1979) had earlier reported annual fluctuations in the diameter of the grasstree caudex beneath the leaf base mantle. Ward (1997) suggested that the coloured bands could form a more convenient method of ageing grasstrees as well as determining the fire frequency at any site where there was a population of grasstrees. It was hypothesised in my project that fluctuations in the nutrient content of the leaf bases would correspond to changes in their colour in response to annual and post-fire changes in nutrient availability. This would lead not only to a greater understanding of nutrient cycling in eucalypt forests, but help verify this new method of ageing and determining the fire history of grasstrees and their associated landscapes.

1.1 GRASSTREES

In Australia, the term grasstree refers to a number of palm-like monocotyledons with spiny leaves belonging to the genera *Xanthorrhoea*, *Kingia* and *Dasypogon* (order Liliales). Classification of grasstree genera at the family level has been controversial. Bedford et al. (1986) and Clifford (1983) classified all grasstree genera in the family Xanthorrhoeaceae. This classification was questioned by a number of authors, including Macfarlane (1987) and Dahlgren et al. (1985), who believe the family to be heterogeneous. Bedford (1987) even contradicted himself later, classifying the grasstree genera into two families, Xanthorrhoeaceae and Dasypogonaceae. Rudall and Chase (1996) reviewed the systematics of the ten genera of Xanthorrhoeaceae *sensu lato* in the light of significant new anatomical and molecular data which indicated that it is a polyphyletic assemblage. They placed *Dasypogon*, *Calectasia*, *Kingia* and *Baxteria* in Dasypogonaceae, *Xanthorrhoea* in the monotypic family Xanthorrhoeaceae, and *Acanthocarpus*, *Chamaexeros*, *Lomandra*, *Xerolirion* and *Romnalda* in Lomandraceae, a family without the grasstree habit. *Xanthorrhoea* is a genus of about 28 species endemic to Australia. There are 8 species in Western Australia, with 7 species endemic to southwest Australia (Bedford et al. 1986). Several of these do not develop the typical grasstree habit.

The common grasstree form in *Xanthorrhoea* is very distinctive, with bright green elongated leaves up to a metre or more in length, cascading from the apex of the plant. The trunk consists of two distinct zones, an inner cortex with scattered vascular bundles and leaf traces, and an outer mantle of tightly packed persistent leaf bases impregnated with resin (Herbert 1920). As grasstrees are often subjected to repeated burning by fires, the stem's surface is usually heavily blackened and the older leaf bases are consequently reduced in length (Staff and Waterhouse 1981). All species have contractile roots and a secondary thickening lateral meristem (anomalous growth) (Bedford et al. 1986). All grasstrees are extremely long-lived and slow-growing (Lamont and Downes 1979). This study focused on *X. preissii*, the most widespread of the grasstrees in Western Australia (Herbert 1920).

1.1.1 Ageing Grasstrees

A number of attempts have been made to age grasstrees. The earliest recorded attempt was by Lewis (1955). He measured the rate of production of leaves over time, and the dimensions of their bases and trunk, to arrive at a growth rate. This gave an unlikely age of 6, 720 years for a *Xanthorrhoea australis* R. Br. plant with its apex at soil level. Gill and Ingwersen (1976) took measurements of the rate of stem elongation of *X. australis*. These calculations gave more realistic estimates of 50 to 350 years since emergence from the soil (Gill and Ingwersen 1976). These attempts were unlikely to be reliable as they depended on measures of growth over a small period of time. Some large grasstrees are sufficiently long lived for their age to be determined by ^{14}C-dating. Ages of 400 to 600 years for *X. preissii* and 750 to 900 years for *Kingia australis* R.Br. were reported by Bell et al. (1984). These figures were recorded by P.R. Wycherley, the results of which remain unpublished. They were based on only one sample per plant and are at the limit of the technique's sensitivity. Nevertheless, they emphasise the potential old age of these arborescent monocotyledons.

The ageing technique used below was developed by David Ward, a senior research scientist at the Western Australian Department of Conservation and Land Management. The inspiration for its development came from a study by Lamont and Downes (1979), in which grasstrees were aged by counting the fluctuations in diameter of the stem's central core (caudex). Alternate expansion and contraction of the apex of *K. australis* and *X. preissii,* produces longitudinal waves of change in stem diameter and morphology each year. The waves are a response to essentially apical growth, and the highly seasonal climate of their native habitat in south-western Australia. These annual fluctuations in stem diameter enable accurate estimation of age and vertical growth rate of individual plants. However, the fluctuations are lost as the lower stem expands with age through (anomalous) secondary growth (Staff and Waterhouse 1981). Lamont and Downes (1979) calculated the mean annual height increase for several plants growing in the Darling Range at 14.2 mm, and estimated an age of 370 years for a 5 m high specimen. To measure the diameter fluctuations it was necessary to harvest the plant and melt the resin adhering to the remnant leaf bases in a large oven so that the leaf bases could be removed.

Ward (1997) discovered that these annual fluctuations on the caudex of *X. preissii* stems correlated with coloured rings on the exterior of the mantle formed by the remnant leaf bases. The stem of a grasstree characteristically has a thick coating of charcoal. The coloured bands may be revealed by removing the outer few millimetres of charcoal and weathered material that initially conceal them. Once revealed, repetitive rings of light brown and dark brown, with occasional black rings, may be seen. It was proposed by

Ward (1997) that the regular rings represented annual growth cycles (light brown - winter/spring growth, and dark brown summer/autumn growth) and the black rings, fire. It is therefore possible to age grasstrees easily and accurately, and to reconstruct fire history for at least the last 200 years. The growth rates calculated from this technique were equivalent to those obtained by Lamont and Downes (1979) in similar locations. An important advantage of David Ward's technique is that the grasstrees do not need to be harvested. It is recognised that the conservation value of very old grasstrees is high.

1.2 THE EFFECTS OF FIRE

The flora of Australia evolved with fire as an integral part of its environment since the late Tertiary period (Kemp 1981). Upon the arrival of aborigines in Australia tens of thousands of years ago, the frequency of fire increased dramatically (Attiwill 1994). Little evidence has been available to determine the frequency of fires prior to European settlement in Western Australia. Some people believe that, before European arrival, the Nyoongar people of south-western Australia made constructive use of fire as a land management tool (Hallam 1975). Attiwill (1994) stated that the frequency of fire increased again following European settlement and since this time fires of catastrophic magnitude have continued. However, Ward (1997) has found in preliminary investigations that the fire frequency appears to have actually declined in the southwest forest since European arrival.

Fire varies in terms of how often it occurs (frequency), when it occurs (season) and how fiercely it burns (intensity) (Bond and van Wilgen 1996). The combination of these three factors describes the fire regime of a particular site. Over evolutionary time, the changes initially produced as short-term or ecological responses to fire become incorporated into the populations as adaptations which better equip the species for its survival in the post-fire environment (Fox and Fox 1987). As a result plant species tend to be adapted to particular fire regimes.

Fire-stimulated flowering is very common in monocotyledons (Bond and van Wilgen 1996), but it is much less common among resprouting dicotyledons (Johnson et al. 1994). It is clear that flowering in a number of Australian species is stimulated by fire, although fire is not essential for the process. Examples include *Blandfordia nobilis* (Johnson et al. 1994), *Macrozamia riedlei* (Bell et al. 1984) and, *Macropidia fuliginosa* and *Anigozanthos pulcherrimus* (Lamont and Runciman 1993). *Xanthorrhoea* spp. are the best known of the Australian flora to exhibit this phenomenon. Gill and Ingwersen (1976) showed that burning is not essential for the production of inflorescences in *X. australis*, but when burnt, flowering occurred approximately a hundred days earlier and more than doubled the number of plants producing inflorescences. The pulse of flowering appears to be closely associated with changes in soil chemistry during the post-fire period (Johnson et al. 1994). Such a relationship is expected in nutrient-impoverished landscapes, where addition of N, P and K (as supplied after fire) may be required before there is a marked growth response (Loneragan and Loneragan 1964). Flowering of *X. preissii* is rare in unburnt bush, but does occur in gardens receiving extra water and fertiliser (Baird 1977). It has been suggested that volatile growth substances, such as ethylene, may be carried in smoke to stimulate flowering in this group of species (Gill and Ingwersen 1976).

1.3 DETERMINING THE HISTORICAL FIRE FREQUENCY

There are few records of the incidence of fire prior to the 1930's throughout south-western Australia. Knowledge of the pre-European fire regime would assist fire ecologists and forest managers in interpreting fire responses and with developing appropriate fire management strategies (Burrows et al. 1995). A number of avenues have been pursued in an attempt to determine the historical incidence of fire. Hallam (1975) completed a thorough literature search on the incidence and nature of burning prior to, and during, the initial stages of European colonisation of the south-west region. Sources for the book included explorers' logs, expedition reports, settlers' journals and letters. All interesting quotes referring to fire were collated from these sources and presented in her book, Fire and Hearth. From these quotes fire frequencies for general areas of the south-west during aboriginal inhabitation were estimated. It should be noted that people of European background have an aversion to fire and it would be expected that their assessment of the severity of aboriginal fires would be exaggerated to some degree (Abbott and Loneragan 1983). Therefore the accuracy of this method for determining fire history has been questioned.

A number of studies have examined the incidence of fire-caused bole injury as an indicator of fire frequency. A 'fire scar' is formed in the trunk of jarrah (*Eucalyptus marginata* Donn ex Sm.) trees from the death of a strip of cambium. New occlusion wood will encase the damaged site, providing the area affected is not extensive and the inter-fire interval is sufficient (3-5 years), making it invisible externally but obvious when the stem is sectioned (Burrows et al. 1995). In a study by Abbott and Loneragan (1983), fire-scars were detected through the presence of dead bark exfoliating and exposing the sapwood on the butt of jarrah trees. The dates of the fires were then determined by counting the growth rings on the stem sections. Only moderate and high intensity fires cause temperatures hot enough to induce the formation of fire scars. An accurate and definitive reconstruction of the fire frequency prior to European settlement was not achieved due to the resilience of jarrah to injury by fire, and the limitations of ring counting as an ageing technique (Burrows et al. 1995). Kino vein formation in marri (*Eucalyptus calophylla* R.Br.) has also been used to determine fire frequency. Kino, an exudate rich in polyphenols, forms veins in many eucalypts following the formation of a tangential layer of traumatic parenchyma (Burrows et al. 1995). Kino veins are formed when the cambium is injured but not killed. This technique is therefore more sensitive to fires of lower intensity, although a complete fire regime is still not guaranteed.

Lamont and Downes (1979) attempted to determine fire history by dating the incidence of floral remnants on *X. preissii* and *K. australis* stems. Floral remnants were considered an indication of fire history due to the association between fires and flowering among grasstrees mentioned above. However, this assumption introduced problems, as not all burnt grasstrees will flower, and some unburnt grasstrees will flower.

It is important to remember that none of the above techniques gives an absolute fire history of a particular site, as the patchiness of fire may have resulted in the plant from which the readings were taken escaping certain fires. Low intensity fires may burn through a forest without igniting the wood on standing trees or stimulating *X. preissii* plants to flower (Anon. 1994).

The technique used by Ward (1997) allows the fire history of a site to be determined by simply dating the occurrence of the black bands on the stem of *X. preissii* and cross-referencing between associated plants. He proposed that this technique is highly accurate as grasstree leaves are highly flammable when dry. It is therefore likely that even low intensity fires will be recorded as a black band, except in frequently burnt sites with tall grasstrees which may escape the fire.

The detection of an accurate fire history could have important implications for the present controlled fire regimes imposed by CALM in areas of the managed forest of Western Australia. The current fire management strategy involves a technique known as prescribed (or controlled) burning, which limits the accumulation of heavy forest fuels and thereby minimises the risk of uncontrollable fires (Underwood and Christensen 1981). At present there is not a complete understanding of the long-term biological effects of either regular fuel reduction burning or more intense burns (Florence 1994). Such fire regimes might conflict with the need to maintain biodiversity. It is stated in CALM's fire management policy that prescribed fire will be used to achieve a range of management objectives, including fuel reduction, habitat management, forest regeneration and the management of scenic values (Anon. 1994). Understanding how past fires have helped shape present-day vegetation is essential when burning programs are devised (Clark 1981).

1.4 NUTRIENT CYCLING

Fire is important in the recycling of nutrients in Western Australian ecosystems. Burning is responsible for loss of nutrients and rapid transfer of nutrients in litter and combustible biomass to soils (Hingston 1985). Soil properties may be altered immediately by a fire, or can be changed by subsequent modifications of vegetation and the activities of soil macro- and micro-organisms (Raison 1979). The intensity, frequency and season of burn, as well as soil and vegetation characteristics, influence the nature and extent of changes in soil chemical properties (Grove et al. 1986). Infertile soils exhibit a general increase in nutrient content following large fuel load fires. This is a common phenomenon in Australia and is referred to as the 'ash-bed effect'.

Grove et al. (1986) found that immediately after fire, concentrations of total and extractable nutrients in surface jarrah forest soils increased markedly. Burning increases surface soil (to a depth of 3 cm) pH, exchangeable Ca^{2+}, organic C, extractable P and other nutrients, following their release from slash and debris (Tomkins et al. 1991). Khanna et al. (1994) showed that the concentration of elements in ash from *Eucalyptus* litter varied several-fold depending upon the nature of fuel (proportion of woody, fine litter and understorey components) and combustion conditions.

As time since fire increases, the levels of the more easily leached nutrients, exchangeable K and Mg, rapidly return to pre-burn values. In contrast, Tomkins et al. (1991) observed that some of the changes, particularly at a depth of 0-2 cm, are relatively long-lived in eucalypt forest: pH, exchangeable Ca and extractable P were still at elevated levels for the high fuel load treatments after 2 years and approximately 2000 mm of rain, whereas more easily leached or utilised cations, such as Na^+ and NH_4^+, fell below the pre-fire levels before recovering.

O'Connell at al. (1979) noted that there was a four-fold increase in the accession of P and N to the forest floor in litter one year after fire in a jarrah forest site. This was due to the increased litter fall after the fire and the increased concentrations of N and P in the post-fire litter. The litter had an increased nutrient concentration as crown scorch prevented the retranslocation of nutrients that normally occurs during leaf senescence. The retranslocation of nutrients during senescence of leaves is an important mechanism for recycling and conserving nutrients within jarrah forest. For both jarrah and marri about 80% of P and 50% of K are apparently withdrawn form the senescing leaf before litter fall (O'Connell et al. 1978). There are only small changes in S, Mg and Na concentrations within the leaf while Ca increases in concentration by about 30% prior to litter fall (O'Connell et al. 1978). This litter fall provides a large source of nutrients to the soil but may come at a cost to the nutrient balance of individual trees. Jarrah forests grow on soils of low fertility where nutrient conserving mechanisms are likely to be crucial for long-term production and functioning of the ecosystem (Grove at al. 1986).

1.5 AIMS OF STUDY

This study had two general aims:

a) to contribute towards the validation of a new method of ageing grasstrees and reconstructing fire histories; and

b) to equate chemical changes in the leaf bases along the lengths of *Xanthorrhoea preissii* stems with season and incidence of fires.

The nutrient concentration of leaf bases was determined in order to define the relationship between fire and nutrient uptake. Chemical analyses should reveal the pattern of build up and possible drop in soil nutrient concentrations over time. The nutrient concentration of grasstree leaf bases may be used to indicate changes in the external nutrient environment as previously achieved with *Macrozamia riedlei* leaves (Grove et al. 1980), a species which often occurs with *X. preissii.*

1.6 HYPOTHESES

The following null hypotheses were tested:

Growth pattern

The light brown bands do not correlate with winter/spring growth.

The dark brown bands do not correlate with summer/autumn growth.

The alternating colour banding along the stems of *X. preissii* do not correlate with annual increments of growth.

The black colour bands along the stem do not correspond to the passage of a fire.

Mineral accumulation

There is no relationship between colour of the bands and mineral nutrient content of the leaf bases.

The incidence of fire has no influence on the mineral nutrient content of the leaf bases.

The season has no influence on the mineral nutrient content of the leaf bases.

Poorly remobilisable nutrients (Ca, Fe, B, Mn), do not show different distribution patterns from the highly remobilisable nutrients (N, P, K, Cu, Zn, Mg).

2. GENERAL MATERIALS AND METHODS

Stems were initially selected according to their length and lack of branching. It was expected that the taller individuals would be older and therefore give a longer time line for fire frequency and nutrient analyses. Branched individuals usually have a more complex arrangement of their leaf bases; this increases the difficulty in removing the leaf bases for nutrient analysis. The outer layer of charcoal and weathered material was ground off prospective stems in the field using a hand-held Metabo 4.5 inch angle grinder and a generator. Once the stems were ground, the final selection was made according to their growth rate and therefore age, and the prominence and arrangement of their colour bands. One stem was selected from each of three sites within the northern jarrah forest.

Three *X. preissii* stems were harvested for analysis. Once selected, the stems were harvested by slicing vertically through the centre of the stem using a chainsaw, the stem was then sliced horizontally a few centimetres above ground level (Plate 2-1). This produced two equal stem halves that were returned to the laboratory for dissection.

The first stem was collected from a jarrah (*E. marginata*) forest site called Gyngoorda block located beside Wandering Rd, North Bannister. The site was 3.1 km east from where the Wandering road intersects with Albany Highway (lat. 32° 35' S, long. 116° 28' E). This stem was the oldest identified and demonstrated very clear coloured banding patterns. The mean annual rainfall for this site is approximately 700 mm/yr, it is included within the northern jarrah forest belt. The fire records for this site only go back to the early 1970's. The most recent fire occurred in the summer of 1984/85; previous to this the only other recorded incidence of fire was in the summer of 1971/72.

The second stem was collected from Poison Gully, a site located 6.8 km east of

Plate 2-1. Collection of the Gyngoorda stem.

where Poison Gully intersects the Brookton Highway (lat. 32° 11' S, long. 116° 15' E). This site had high annual rainfall; 950 mm/yr and was located in the belt of jarrah forest on the Darling Scarp. This stem was the exception to the above stated criteria as it was branched. Therefore dissection was not attempted beyond the point where the branching began as identification of the coloured bands was unreliable. The past incidences of fire are unknown at this site.

The third stem was collected from a site known as the Amphion Forest Block. This site was in the heart of the northern jarrah forest, 19 km by road east of Dwellingup (lat. 32° 48' S, long. 116° 12' E). The mean annual rainfall at this site is very high;

approximately 1100 mm/yr. This site has had fire actively excluded since 1932 i.e. for 66 years. The stem lacked black bands for the majority of its length.

On return to the laboratory, one half of each stem was stored as it was not required for this study. The remaining stem halves were reground so that the coloured bands were easily distinguishable (Plate 2-2, Plate 2-3). Each stem was then photographed so that the prints could be used for colorimetric analysis (see later). Every set of one light brown band and one dark brown band were marked using a felt pen. The stem was aged and the frequency of fire calculated. The stem was then photographed again for future reference.

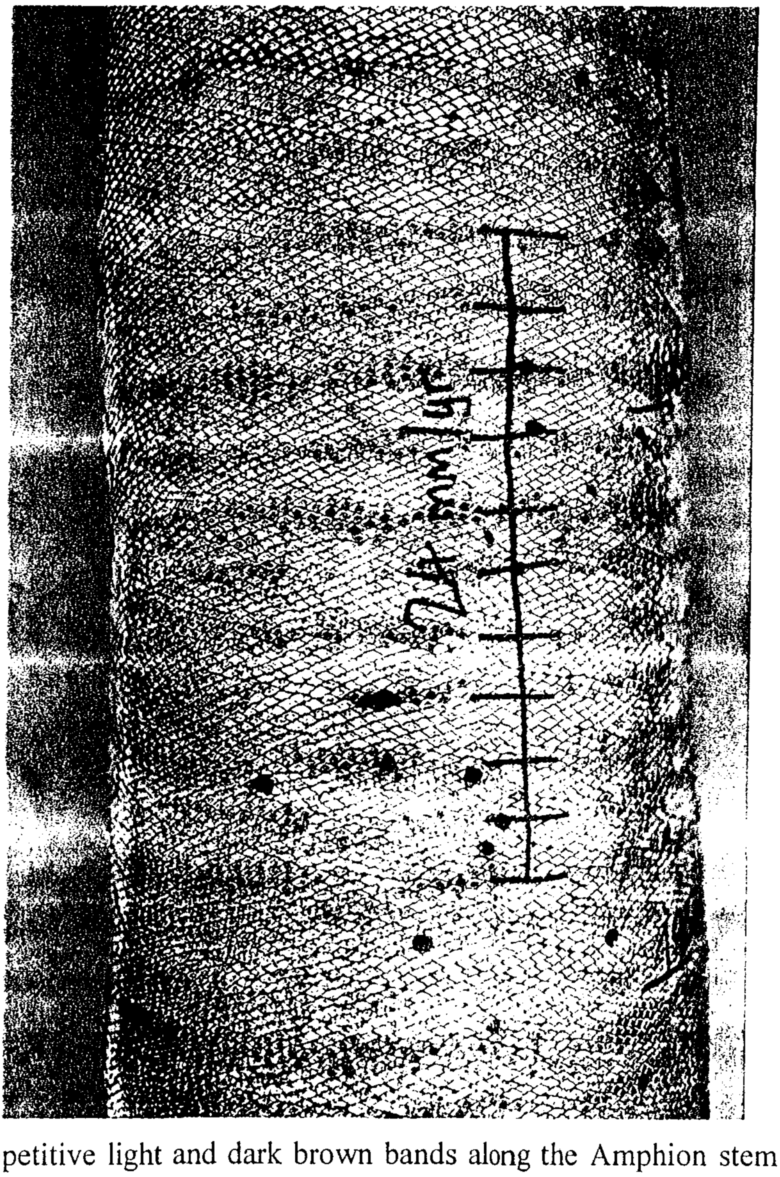

Plate 2-2. Repetitive light and dark brown bands along the Amphion stem. (The red lines on the extreme right of the stem indicate the years 1960 and 1950. The mean growth rate over this decade is indicated. No black bands are present in this photograph as the Amphion stem has not been burnt for over 60 years. Width across stem was 240 mm.)

Plate 2-3. The irregular black bands are clear on this ground *X. preissii* specimen. (Width across stem was 290mm.)

Once all the colour bands had been aged, the remnant leaf bases composing each light brown, dark brown and black band along the length of the stem were dissected out, bagged and labelled. The leaf bases were removed by using a Makita Thermocouple Heat Gun (2000 W) to melt the resin that bound the bases together and then pulling them from their site of attachment. Once the resin was melted the leaf bases were quite easily removed. The leaf bases were stored in paper bags, so that each bag contained the leaf bases for an individual colour band. The numbers and length of leaf bases constituting each band varied, generally the range was 20 to

30 leaf bases, 4.5 to 6 cm in length. The samples within each bag were cut, ground and submitted for nutrient analysis.

Only half of the leaf bases composing each colour band were removed. This left the stem with leaf bases remaining on one side and the stem fluctuations exposed on the other. The relationship between the colour bands and the stem fluctuations was therefore easily noted for all 3 stems. The width of each colour band and stem fluctuation was measured and recorded.

3. TECHNIQUE VALIDATION

3.1 INTRODUCTION

The technique employed for ageing grasstrees has yet to be formally validated. This is a direct result of the infancy of the project, and therefore, no publications have yet been produced. However, Ward and Van Didden (1997) produced an unpublished report on results from a preliminary small-scale study. A project canvassing a large number of grasstrees in diverse habitats throughout the south-west is currently underway and a manuscript is expected late in 1998. This publication will compare the dates of recent fires as indicated by the black bands on grasstrees, with the formal records from CALM and the Forests Department, and from oral history. If the black bands and the formal records of fire correlate, the technique will be satisfactorily validated. In the meantime, partial validation will be provided using a range of approaches.

The black coloration of the leaf bases after the passage of fire is thought to be due to the presence of lapachol (2-hydroxy-3-(3-methyl-2-butenyl),1,4-naphthalenedione) (Challinor 1996). Preliminary analysis, using pyrolysis gas chromatography, concluded that lapachol was present in the black leaf bases, but absent in the light and dark brown ones. It is thought that the black bands are formed when green leaves are killed during a fire event (Ward 1997). Therefore it is suggested that the lapachol, or a precursor molecule, is trapped within the leaf base by fire and prevented from either being retranslocated upon senescence, or decomposing with age to its constituents.

Preliminary findings using this technique indicate that the aborigines burnt much of the jarrah forest every 2 to 4 years prior to European settlement (Ward 1997). It is important to note that these results are biased toward the moist drainage lines where grasstrees are most abundant (Ward 1997). The frequency of fire in these areas may have been higher than average due to the proliferation of the ignition source, the

Nyoongar aborigine. Aborigines regularly travelled along such drainage lines due to the availability of water and food (Hallam 1975). Current research is designed to ensure that data are collected throughout the landscape. The historical fire frequency indicated by the three stems studied is presented below.

3.1.1 Colorimetric analysis

The preliminary results of this project have met a range of responses among the scientific community. It has been suggested that the existence of the coloured bands is unclear. Therefore this section involves the analysis of the stem with a colour meter to detect objectively the presence of the colour variation.

3.1.2 Correlation of stem fluctuations and coloured bands

This section was completed to confirm that the coloured bands formed by the mantle correspond with the cortex fluctuations reported by Lamont and Downes (1979). This test used the human eye to determine whether the fluctuations and the corresponding bands are produced during equivalent periods of growth.

3.1.3 Do the two colour bands represent annual increments of growth?

The correlation of the width of one year's growth calculated from the stem fluctuations, represented by one peak and one trough, with the putative annual growth determined from the coloured bands, represented by one light brown and one dark brown band, was tested. Lamont and Downes (1979) previously confirmed that the stem fluctuations represent annual growth cycles. Therefore if the widths are equivalent, it would be concluded that one light brown and the adjacent dark brown band are the equivalent of one year's growth. Counting the coloured bands would therefore give an accurate measure of stem age.

3.1.4 Fire history

It is proposed that analysis of the position of the black bands along a *X. preissii* stem will enable fire history to be calculated. If fire records obtained from CALM, the Forests Department and oral history correlate with the proposed incidence of fire calculated from the black bands it may be concluded that the black bands are the product of the passage of fire. Long-term changes in fire frequency could then be calculated.

3.2 MATERIALS AND METHODS

3.2.1 Colorimetric analysis

Colour photographs were taken of the length of the three grasstree stems. Readings could not be taken directly from the stem due to the scabrous nature of the surface, even after sanding. The photographs were enlarged and colour A4 sized mat prints produced. The colour intensity was then measured every 2 mm along the length of the photograph using a ColorTec-PCM, New Jersey, USA colour meter. The meter gave a quantitative measure of the Hunter L,a,b spectra for the intensity of each colour group at each point. Hunter L,a,b is a three-dimensional co-ordinate scale of colorimetric readings where the L co-ordinate corresponds to lightness (relative to the Y axis), the a co-ordinate corresponds to redness (positive) or greenness (negative), and the b co-ordinate corresponds to yellowness (positive) or blueness (negative) (ColorTec 1995).

The photographs were illuminated by fluorescent tubes and the colour meter was set to take this into account. Light intensity measurements were taken using a LI-COR Model LI-185B light meter with a fish eye quantum sensor (300-700 nm range) to ensure that colour measurements were recorded at a relatively constant light level. Variation was limited to the range 1.6 to 1.7 μ mol $m^{-2}s^{-1}$ for the duration of the analysis time.

3.2.2 Correlation of stem fluctuations and coloured bands

After the remnant leaf bases were removed from the stem, the oscillations in the caudex were exposed. To determine whether the stem fluctuations correlated with the coloured bands the remnant leaf bases from each colour band were followed down to their point of attachment for all 3 stems. It was noted whether this point was situated on the peak of a fluctuation, in the trough, or on the slope between a peak and a trough. The results were analysed using a chi-square test of independence at a significance level of 0.01. The statistic, Cramer's *V*, was calculated to determine the strength of any relationship that the chi-square found. All the raw data and statistical output for Chapter 3 have been included as Appendix 1.

3.2.3 Do the two colour bands represent annual increments of growth?

The width of each annual colour band was recorded by measuring the distance between the mid-point of a light brown band to the mid-point of the next successive light brown band. This was compared with the annual increments calculated from the stem fluctuations, which were recorded by measuring the distance between the peak of a stem fluctuation and the peak of the next successive stem fluctuation. All distances were measured using vernier calipers to the nearest 0.1 mm. The means of these distances were compared using a *t*-test for paired samples at a significance level of 0.05.

3.2.4 Fire History

Each of the stems was aged using the assumption that the light brown bands represent winter/spring growth and the dark brown bands summer/autumn growth. The date of the occurrence of the more recent black bands, which were covered by the limited fire records, were correlated with the known fire events at that site. For example, it was known from records held at CALM that the Gyngoorda site had been burnt in the summer/autumn of 1984/85 and 1971/72. Therefore the top two black bands were marked with the corresponding years, 1984/85 and 1971/72, and the stem was aged using these two black bands as reference points. The number of annual growth cycles (light brown and dark brown bands combined) between these two fire events was counted to see if the figure was equal to the number of years that had passed between them.

3.3 RESULTS

3.3.1 Colorimetric analysis

The Hunter *L* co-ordinate produced values that coincided with the cycle of the light brown and dark brown bands along the length of all three stems. Figure 3-1 displays the oscillation of the lightness values recorded along the Gyngoorda stem. The larger *L* values represent the light brown bands, the lower values the dark brown and black bands. In Figure 3-1 there are 11 peaks which represent 11 light brown bands and 10 troughs which represent 10 dark brown bands.

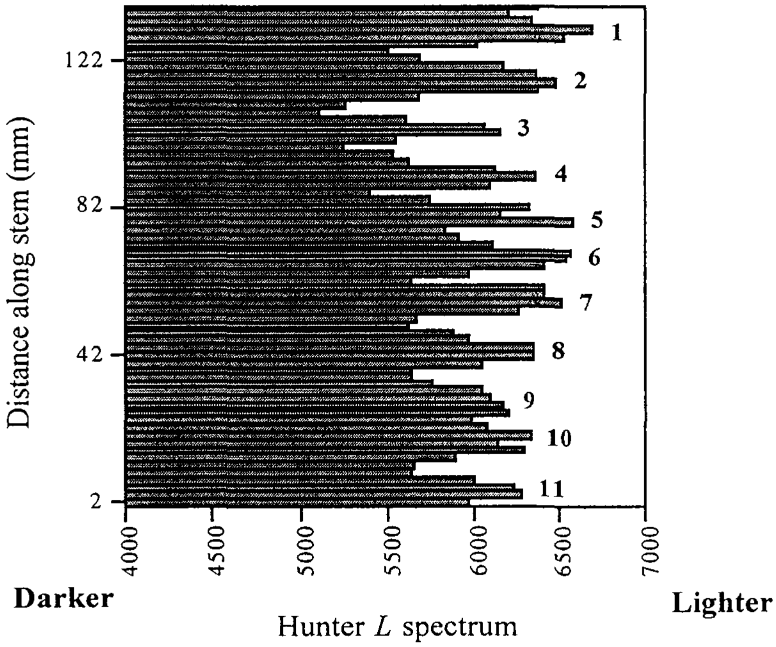

Figure 3-1. Hunter's *L* co-ordinate values, measured at 2 mm intervals along the length of the Gyngoorda stem. The eleven light brown bands (peaks) have been numbered.

Hunter's *a* co-ordinate corresponding to redness (positive) or greenness (negative) did not indicate any definite trends for any of the three stems. Figure 3-2 is an example of the values recorded. It shows the random oscillations along the Amphion stem. In general, the colour bands gave values more towards the red end of the spectrum than the green.

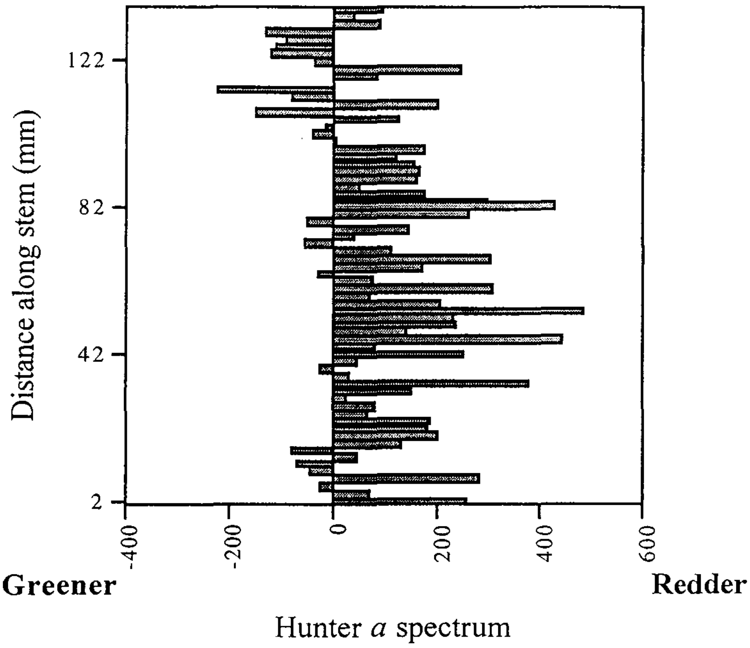

Figure 3-2. Hunter's *a* co-ordinate values, measured at 2 mm intervals along the length of the Amphion stem.

Hunter's *b,* corresponding to yellowness (positive) and blueness (negative), displayed a pattern of change consistent with the cycle of the light brown and dark brown bands. Figure 3-3 displays the *b* co-ordinate values along the length of the Amphion stem. The peaks in the *b* spectrum values represent the dark brown colour bands, which are therefore more towards the yellow end of the spectrum. The troughs represent the light brown bands which are more towards the blue end of the spectrum. The number and width of the bands recorded by the *b* co-ordinate correspond to those recorded by the *L* co-ordinate. As seen in Figure 3-3, 12 light brown bands (troughs) and 12 dark brown bands (peaks) occurred along the length of the Amphion stem measured (136 mm).

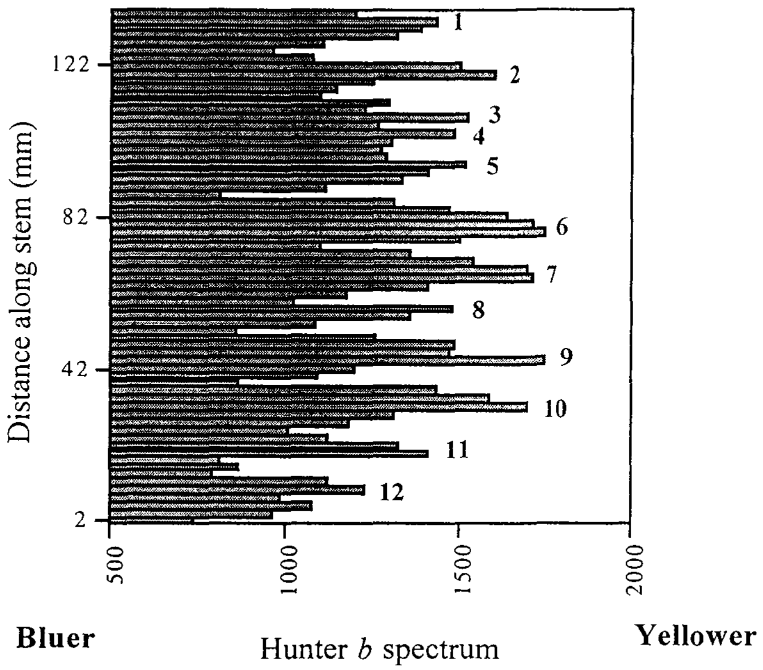

Figure 3-3. Hunter's *b* co-ordinate values, measured at 2 mm intervals along the length of the Amphion stem. The 12 dark brown bands (peaks) have been numbered.

3.3.2 Correlation of stem fluctuations and coloured bands

A chi-square test of independence was performed on the Gyngoorda stem data (Table 3-1). The chi-square test calculated a *P*-value of 0.0001, confirming that the coloured bands do correspond with the stem fluctuations. For the Gyngoorda and Poison Gully analyses, 33% of the cells had expected frequencies less than 5. These cells contributed very little to the total chi-square value, enabling the test still to be employed, without risking falsely rejecting the null hypothesis.

Table 3-1. Chi-square table comparing the counts of the correlation of the stem fluctuations with the colour bands along the length of the Gyngoorda stem.

Colour of band	Peak	Trough	Incline
Light brown	14	1	2
Dark brown	0	14	2

Cramer's *V* was calculated to measure the strength of the association between the colour bands and the stem fluctuations. Cramer's *V* lies in the interval from 0 to 1 with a value of 0 showing no association and 1 when the two variables are perfectly associated. The value calculated from the Gyngoorda stem data was 0.875. Therefore, it can be concluded that the association between the colour bands and the stem fluctuations is very strong.

For the Poison Gully stem a chi-square *P*-value of 0.0001 was also calculated. This once again supports the assumption that the stem fluctuations and the coloured bands are dependent. In both Table 3-1 and Table 3-2 the light brown bands correlated with the peak of the stem fluctuations and the dark brown bands correlated with the troughs.

Table 3-2. Chi-square table comparing the counts of the correlation of the stem fluctuations with the colour bands along the length of the Poison Gully stem.

Colour of band	Peak	Trough	Incline
Light brown	17	1	2
Dark brown	2	17	1

The Cramer's *V* value calculated for the Poison Gully stem was 0.812. This confirms that there is also a strong relationship between the stem fluctuations and the colour bands for this stem.

With a chi-square *P*-value of 0.0001, it was concluded that the stem fluctuations and the colour bands are also dependent on the Amphion stem. However, the peaks of the fluctuations correlated with the dark brown bands and the troughs with the light brown bands (Table 3-3). This contradicts the trend seen in the previous two stems.

Table 3-3. Chi-square table comparing the counts of the correlation of the stem fluctuations with the colour bands along the length of the Amphion stem. (No correlations with the Incline were recorded within this stem.)

Colour of band	Peak	Trough
Light brown	1	13
Dark brown	12	1

The Cramer's *V* measure was calculated from the Amphion stem data presented in Table 3-3. A value of 0.852 was calculated, also supporting the conclusion that the stem fluctuations and the colour bands are strongly related.

3.3.3 Do the two colour bands represent annual increments of growth?

At a significance value of 0.05, a paired *t*-test indicated that the distances from peak to peak and from white band to white band were not significantly different for all three stems (Table 3-4). This provides further evidence to confirm that the stem fluctuations and the colour bands are correlated. However, the widths measured for the coloured bands were consistently, but not significantly, wider than those measured for the stem fluctuations.

Table 3-4. The mean distance (mm) from peak to peak of stem fluctuations and band to band of corresponding colour, for each of the 3 stems.

Stem source	Peak to peak (mm)	Band to band (mm)	*P* (2-tailed)
Gyngoorda	14.2 ± 2.7	14.4 ± 3.1	0.657
Poison Gully	19.0 ± 2.4	19.6 ± 2.0	0.072
Amphion	26.0 ± 1.5	26.2 ± 1.8	0.513

On the Poison Gully stem the average distances between the peaks and between the white colour bands were greater than those recorded from the Gyngoorda stem, with mean differences of 4.8 mm and 5.2 mm respectively (Table 3-4). The Amphion stem had distances even greater than the Poison Gully stem. On average Amphion's peak to peak values were 7.0 mm greater and the band to band values were 6.6 mm greater (Table 3-4).

3.3.4 Fire history

3.3.4.1 Gyngoorda Block

The Gyngoorda stem was aged at over 100 years. The period from the putative years 1891 to 1988 was intensively studied due to extreme 'faulting' (displacement of parts of the bands vertically) in the stem below this point. The Forests Department recorded occurrences of fire, 1971/72 and 1984/85, were confirmed by the number of brown bands between the two black markings. Twelve sets of the putative annual bands were counted between the 1971/72 fire and the 1984/85 fire, which is equal to the number of years that had passed. Therefore, the first suggestion that one light brown band and one dark brown band are the equivalent of one year's growth, and the second suggestion that each black band represents the passage of fire, are further supported by this evidence.

A total number of 20 black bands was recorded for the 1890 to 1988 period, the entire length of the stem studied. An overall fire frequency of 1 per 4.9 years was therefore calculated for the Gyngoorda site. This is a misleading figure though, as a high proportion of the fires recorded were concentrated in the lower half of the stem. It is best to calculate the frequency of fire for each decade individually (see Table 3-5). The figures presented within Table 3-5 indicate a decrease in the frequency of fire over time.

Table 3-5. The frequency of fire per decade for the Gyngoorda site.

Decade	Number of fires recorded
1890 to 1899	3
1900 to 1909	4
1910 to 1919	3
1920 to 1929	2
1930 to 1939	2
1940 to 1949	2
1950 to 1959	2
1960 to 1969	0
1970 to 1979	1
1980 to 1989	1
1989 to 1997	0

3.3.4.2 Poison Gully

Fire records for the Poison Gully site are inconsistent as a number have been destroyed. Therefore, there is only a limited period of time where both the Forests Department records (stemming from local knowledge and the limited records remaining) and the grasstree stem record are available. Comparisons between the two can only be made within the years 1968, where the human record begins, and 1979, where the grasstree stem record ends. The Forests Department has not recorded a fire within this period. This is supported by the grasstree stem, as no black bands occurred within this time span either.

A total of five fires was recorded by the grasstree stem taken from Poison Gully, for the duration 1928 to 1979, a period of 51 years. An average fire frequency, calculated over the entire stem, gave a value of 1 per 10.2 years. This figure is again misleading when the frequency of fire per decade is considered (Table 3-6). Even though fewer fires have occurred at this site as compared with the Gyngoorda site, the downturn in the frequency of fire over time is still clear. The black bands always occurred in between adjacent light brown bands, where a dark brown band would have normally been. It was therefore assumed that all of the fires occurred in the summer/autumn period. Fires were recorded in the summer/autumn of 1933/34, 1936/37, 1942/43, 1948/49 and 1958/59.

Table 3-6. The frequency of fire per decade for the Poison Gully site.

Decade	Number of fires recorded
1930 to 1939	2
1940 to 1949	2
1950 to 1959	1
1960 to 1969	0
1970 to 1979	0

This analysis could not be applied to the Amphion stem as CALM have actively excluded fire from the site. A fire has not occurred for 66 years; the last was in the summer of 1931/32.

3.4 DISCUSSION

3.4.1 Colorimetric analysis

The fluctuations from darker to lighter, determined by Hunter's *L* spectrum, correspond with the repetitive cycles of the coloured bands along the length of each of the three stems measured. The results of Hunter's *b* spectrum further demonstrate the cyclic colour variation. Therefore, quantitative evidence confirming the existence of the colour bands has been produced which should dispel any doubt regarding their existence.

3.4.2 Correlation of stem fluctuations and coloured bands

The strong correlation of the colour bands with the stem fluctuations confirms that they are produced during equivalent periods of growth. Lamont and Downes (1979) have previously confirmed that the stem fluctuations are annual increments. It is therefore suggested that the combination of one light brown band and one dark brown band is the equivalent of one years growth, as demonstrated with the peak and the trough of the stem fluctuations. The reverse correlation seen in the Amphion stem is very surprising and the cause is as yet unknown. Further sampling and research within the Amphion site may lead to the explanation of this anomaly.

3.4.3 Do the two colour bands represent annual increments of growth?

The width of the annual increments calculated from the caudex fluctuations were not significantly different from those calculated from the colour bands for all three stems. Therefore, it is confirmed that the stem fluctuations and the colour bands correlate, and that the colour bands do indeed represent annual growth increments. The widths of the coloured bands were slightly wider than those measured from the stem fluctuations. This is probably due to post-harvest shrinkage of the caudex, and spreading of the remnant leaf bases when adjacent leaf bases were previously removed using the hot air gun.

The colour variation within the growth bands may be due to strongly seasonal growth, characteristic of the flora of southwest Australia. Tree stem growth is limited to a single growing season each year due to the strong Mediterranean-type climate typical of the jarrah forest region (Burrows et al. 1995). The winter/spring growth flush seen within many habitats is a response to water availability and warm growing conditions over these seasons. Burrows et al. (1995) stated that the slow growth at the end of autumn and beginning of winter produces a narrow band of dark wood, followed by a wider band of faster grown lighter coloured wood - these bands form the growth rings of *E. marginata*. Therefore it is suggested that, within the less seasonally restricted growth of *X. preissii*, the light brown bands (the peaks) represent winter/spring growth, and the dark brown bands (the troughs) represent summer/autumn growth. This is supported by the conclusions of Lamont and Downes (1979), Lamont (1981) and Twaddle et al. (1978).

Lamont and Downes (1979) found that most leaf development and associated stem expansion occurs in the winter/spring growing season. Therefore, the peaks of the stem fluctuations would be the result of this winter/spring expansion of the caudex. Evidence of a winter/spring flush is also provided by Lamont (1981), after growth measurements were recorded from *K. australis*. It was also suggested by Twaddle et al. (1978) that the peaks were the result of winter/spring growth. The $^{12}C/^{13}C$ ratio in leaf bases was measured by mass spectrometry. The rise and fall of the ratio within each wave was consistent with the seasonal temperature changes for the region (Twaddle et al. 1978). The temperatures calculated within the peaks were consistent with those experienced within the cooler winter/spring months. It is therefore concluded that the peaks, and therefore the light brown colour bands are the result of winter/spring growth. The troughs and the corresponding dark brown bands are the equivalent of summer/autumn growth.

The mean growth rates recorded were consistent with those recorded by Lamont and Downes (1979). A mean height increase of 19.7 mm yr^{-1} was recorded in this study, while Lamont and Downes (1979) reported 14.2 mm yr^{-1} for *X. preissii* stems of varying heights, from a wide range of habitats. Gill and Ingwersen (1976) recorded a mean rate of stem elongation of 9.0 mm yr^{-1} for *Xanthorrhoea australis* stems at Tidbinbilla Nature Reserve near Canberra.

Highly variable growth rates for *X. preissii* have been recorded previously between sites. The slowest average growth rate, measured over a 250 mm section of stem by Lamont and Downes (1979), was 10.6 ± 2.0 mm yr^{-1} and the fastest was 23.9 ± 4.0 mm yr^{-1}. This is due to the wide distribution of *X. preissii* throughout a range of Western Australian habitats. The greatest mean growth rate of 26.0 mm yr^{-1} was recorded for the Amphion stem. This can be attributed to the higher mean annual rainfall at this site.

3.4.4 Fire history

The supposition that the black bands are the result of the passage of fire is confirmed by all the results for the Gyngoorda and the Poison Gully stems. The absence of black bands since 1932 along the length of the Amphion stem is also confirmation that the black bands are formed from the passage of fire. Therefore, the fire history at any site where there is a remnant population of grasstrees may be determined, relieving the lack of definitive historical fire records within the majority of Western Australian ecosystems. Such information would allow ecologists to determine how different fire frequencies have shaped the vegetation. In the past such studies have relied solely on the time that has passed since the last fire occurred. However, a study of fire should be based on an investigation of the effects of a sequence of fires, because at least two fires are required to estimate fire frequency (Cary and Morrison 1995). Bradstock et al. (1997) suggested that differences in fire regimes among sites before consistent historical records could account for unexplained variation that they found in floristic composition.

The impact of different fire frequencies on the vegetation would be very valuable information for determining management options. The long-term effects of frequent low intensity fires, irregular conflagrations and other variations of fire regime could be defined. Knowledge of the relationship between fire regime and persistence of populations of species must form the basis of management for conservation (Bradstock et al. 1996); at present such knowledge is meagre. Contrasting the differences in species composition, vegetation demography and vegetation structure between two adjacent sites that have experienced different fire regimes would allow the long-term effects of fire to be evaluated. The common assumption that the presence of long-lived dominant species suggest lengthy fire cycles, and that resprouting or abundant seedling regeneration indicates relatively short fire cycles (Fox 1998), could also be assessed.

The results indicate a gradual decrease in the frequency of fire over the last 100 years. The history of the Gyngoorda block in relation to its fire frequency has been summarised by Ward (1997). Downturns in fire frequency are believed to have resulted from the cessation of traditional aboriginal burning practices following the Bushfire Act of 1847 (flogging or prison), measles epidemics affecting the aborigines in the 1860s and 1880s, passing of the Forests Act in 1918, fire exclusion by the then Forests Department (1920s and 1930s) and prescription burning (1962 to present) (Ward 1997, Burrows et al. 1995, Underwood and Christensen 1981). These events are supported by the fire frequency trends determined on both of the stems analysed.

It has been suggested that this technique may not be capable of recording the passage of low intensity fires. This is a common problem when using fire scars on tree stumps, and flowering remnants on *X. preissii* stems (Lamont and Downes 1979) as indicators of the passage of fire. Low intensity fires can regularly burn through the forest without igniting the wood on standing trees or stimulating blackboys to flower (Anon. 1994). It is suggested that the thatch of tall *X. preissii* stems may not be ignited from low intensity fires, therefore not producing a black band of remnant leaf bases. However, juvenile (shorter) specimens would be ignited, therefore if cross-referencing, and sampling throughout the age classes of the population is employed, the results would be more reliable.

Now that the validity of the technique has been supported it can be widely employed to provide information on fire regimes. The analysis of stems of greater ages would allow the frequency of fire to be determined even further into the past, providing information on how frequently aborigines burnt the bush. Ward (1997) has reported fire histories back to 1750 with this technique, over 100 years before European influences on the vegetation.

4. NUTRIENT ANALYSES

4.1 INTRODUCTION

Post-fire foliage is usually nutrient rich relative to that prior to fire. Grove et al. (1980) showed that concentrations of N and P in *Macrozamia riedlei* leaves, and P, K and Zn in their surface roots, were significantly higher in plants growing in recently burnt forest. However, concentrations of Ca, Na and Cl in leaves were higher at sites that had not been burnt recently. Both between and within species differences in nutrient concentrations have been attributed to variations in nutrient availability in the rooting medium (Foulds 1993). Few studies have examined variations in plant nutrient concentration over time. However, Guyette et al. (1992) employed dendrochemistry techniques on trees to infer long-term changes in soil pH.

The nutrient contents of the remnant leaf bases along the length of three *X. preissii* stems were analysed in my study. This was expected to provide information on the long-term cycling of nutrients within plants in relation to the passage of fire and seasonal variation. Soil samples were collected so that any large variation in the nutrient content of the leaf bases between sites might be explained.

Due to the expense involved in chemical analyses extensive replication was not possible. Three stems from separate sites were analysed. With more time and funding, replication within each site could have been undertaken. Trees from separate sites were studied so that any seasonal and annual variations would not be confounded by a site effect. If three stems from within the same site had been analysed it would be impossible to distinguish whether the variation was due to peculiarities of that site.

4.1.1 Nutrient list

The nutrient analyses of the leaf bases required determining the concentration of the 12 elements listed below. Some background information on each is provided so that the results may be readily interpreted.

4.1.1.1 Phosphorus

P is a macroelement that enters the root in various phosphate forms. P is contained within amino acids, nucleotides and macromolecules composed of them (proteins, DNA, RNA). It plays an important role in the energy metabolism of the cell (Mohr and Schopfer 1995). In acidic soils most of the inorganic P occurs as relatively insoluble Fe and Al phosphates, and in association with clay minerals (Sutcliffe and Baker 1974). P is immobile as soils derived from laterite are highly sesquioxidic and they fix P very strongly (Attiwill and Leeper 1987). In contrast to this, P is highly mobile within plant tissues.

Australian soils generally have a low content of P by world standards (Williams and Raupach 1983). Following leaching over millions of years, the only residual P in the soil is very tightly bound (Attiwill and Leeper 1987). The native vegetation is adapted to these low nutrient levels (see Lamont 1982; Lamont 1984), and does not appear to limit growth rates. Most of Australia's flora is highly efficient at retaining P within the plant through internal redistribution, termed biochemical cycling (Handreck 1997). This efficient internal recycling is believed to be an adaptation to low nutrient availability in the substrate.

Fire has varying effects on the concentration of P within forest soils. P may be lost through volatilisation (Handreck 1997); the amount lost is directly correlated with fire intensity. Fine white ash contains concentrations of P up to 50 times higher than levels in unburnt litter (Raison et al 1985a). Therefore, a small loss of ash can result in substantial export of P. Even though fire induces losses of P from the system, the levels of plant available P increase. Humphreys and Lambert (1965) noted that soil P fractions were changed considerably in the direction of greater availability to plants when a forest soil (sandy loam) was heated at 350°C for four hours. Fire induces remineralisation of the tightly bound P component.

4.1.1.2 Calcium

Ca is a macroelement; and a component of pectins in the cell wall (Mohr and Schopfer 1995), it is also an important factor in the structural integrity of membranes. Alternatively Ca may occur as crystalline deposits of insoluble calcium salts, such as calcium oxalate, in the cytoplasm (Sutcliffe and Baker 1974). Ca is not phloem-mobile (Foulds 1993), therefore it is not redistributed after its initial deposition within the leaf. Ca continues to accumulate until leaf senescence, upon which, it is lost to the plant on leaf fall.

The uptake of Ca is in the form of ions from the soil solution (Taiz and Zeiger 1991). The relative amounts of exchangeable cations in forest soils follow the order Ca>Mg>K>Na (Attiwill and Leeper 1987). Ca is relatively immobile within the soil. Soil calcium exerts a strong influence on pH; with an increase in Ca there is also an increase in pH (McColl 1969).

As the organic matter of the surface soil and soil bound nutrient reserves are mineralised, Ca concentrations are increased immediately after the passage of fire. Ca is often the most abundant element in plant ash. High concentrations of Ca in the soil usually cause a reduction in the levels of other nutrients: K, Na and P (Sutcliffe and Baker 1974). Calcium accumulation is inhibited by the presence of Rb, K, Na, Al, and Mg. Ca is susceptible to erosional losses but not to soil leaching losses. Large amounts of Ca^{2+} are released following burning but move more slowly through the soil profile (Tomkins et al. 1991), due to low mobility.

4.1.1.3 Potassium

K is a macroelement that most probably always exists as a free cation. The large quantity of K makes it the dominant inorganic ion in the plant cell (Mohr and Schopfer 1995). K is a mobile carrier of positive charges and acts as a cofactor of enzymes. Uptake of K is in the form of ions from solution (Taiz and Zeiger 1991). K is regarded as highly phloem-mobile (Foulds 1993). K is readily remobilised from old leaves (Attiwill and Leeper 1987) and leached from old or dead leaves (O'Connell et al. 1978). The highest levels of throughfall for all the nutrients have been recorded for K. K leaches very little from the soil (Jakobsen 1996). K accumulation may be inhibited by Ca and Mg as the latter two have greater competing power when present in equivalent amounts (Attiwill and Leeper 1987). K may act to inhibit the accumulation of Na (Fried and Broeshart 1967).

The passage of fire causes a flux in the availability of K within forest soils, even though large non-particulate losses of K are possible. The duration of the increases in cation levels is related to their mobility and the occurrence of rainfall subsequent to burning (Tomkins et al. 1991). Cation exchange reactions prevent the soluble K from moving beyond the root zone (Richards and Charley 1983), so K increases are retained for a limited period. K is susceptible to particulate losses from the post-fire environment, Hall (1994) recorded 20 times more K lost in runoff from burnt plots.

4.1.1.4 Magnesium

Mg is a macroelement that is a component of pectins in the cell wall (Mohr and Schopfer 1995). Mg is a constituent of some organic molecules, including chlorophyll, and also occurs as free ions in the cell sap (Sutcliffe and Baker 1974). Uptake of Mg is in the form of ions from solution. Mg varies a lot between species and within species on different soils (O'Connell et al. 1978). Mg displays partial mobility within plant tissues. Under certain conditions, it may be withdrawn to a limited extent prior to abscission (Sutcliffe and Baker 1974). Litterfall is usually the major pathway for the return of Mg to the soil, although moderate amounts of Mg are leached from tree crowns (Adams and Attiwill 1986).

The concentration of Mg is highly variable within forest soils. In most soils, cation exchange reactions prevent soluble Mg from moving beyond the root zone (Richards and Charley 1983). Where the Ca:Mg ratio is less than 1, Mg may compete with Ca to the extent of limiting growth (McColl 1969). However, when the ratio is greater than 1, as is usually the case, Ca will out compete Mg. Mg is a dominant cation in plant ash. Raison et al. (1985b) recorded a 10- to 35-fold increase in the concentration of Mg within fine (< 1 mm) ash produced after a low-intensity prescribed fire at a *Eucalyptus pauciflora* Sieb. ex Spreng site. An immediate effect of fire on the surface soil is to increase pH (since CaO and MgO are dominant in the ash) and to increase the availability of nutrients in the surface soil (Attiwill and Leeper 1987). Non-particulate losses and leaching losses of Mg occur on a limited scale. However, particulate losses may be substantial. Hall (1994) recorded approximately 100 times the Mg^{2+} lost from burnt plots than from control plots.

4.1.1.5 Sulfur

S is a macroelement that is absorbed by the root in the form of sulfate. S is contained in some amino acids, nucleotides and macromolecules composed of them (proteins, DNA, RNA) (Mohr and Schopfer 1995). S is moderately mobile within plant tissues, average levels are withdrawn from senescing leaves prior to abscission (O'Connell et al. 1978). Inorganic S occurs almost entirely as sulfate, which may be adsorbed on the soil colloids, or be present as either water-soluble salts or as insoluble sulfate associated with calcium carbonate (Williams and Raupach 1983). Soluble sulfate is very mobile in most soils and is therefore quickly leached from the root zone. When organic matter is burnt some of the S which it contains oxidises to sulphur dioxide and is lost to the atmosphere (Humphreys and Craig 1981). Non-particulate losses may be replaced by accessions of S in rainfall (Hingston 1985). Even though volatilisation of S occurs during combustion, an increase in S availability within the soil still occurs. These elevated S levels are short lived, as a significant proportion of the nutrient released from burning is lost either through erosion and runoff, or through leaching (Juo and Manu 1996).

4.1.1.6 Boron

B is a microelement and its uptake is in the form of boric acid or borate (Taiz and Zeiger 1991). Boron is unique among the essential plant nutrients in that it has restricted mobility in many plant species and yet is freely mobile in others (Brown and Shelp 1997). However, in the majority of plant species, B distribution between plant organs and the symptoms of B deficiency and toxicity indicate that B has restricted mobility (Brown and Shelp 1997). The bulk of B generally remains within the leaf and is lost to the plant on leaf fall. The availability of B increases after the passage of fire, even though high non-particulate transfers occur during combustion (Raison et al 1985b). B may be readily leached from soils after additions in the form of ash (Gangloff et al. 1997).

4.1.1.7 Copper

Cu is a microelement, whose uptake is in the form of ions or chelates from the soil solution (Taiz and Zeiger 1991). Cu is a component of several metallo-enzymes in plants. Little Cu is mobilised from the leaf before litter fall (Bowen 1981). Bivalent Cu ions are strongly adsorbed onto clay particles in an exchangeable form and they also form stable complexes with organic molecules (Sutcliffe and Baker 1974). Due to the immobility of Cu within the soil, transfer to the root may be limiting (Bowen 1981). When burning occurs concentrations of Cu rapidly increase within the soil (Ahlgren and Ahlgren 1960).

4.1.1.8 Iron

Fe constitutes part of the haem proteins (Mohr and Schopfer 1995). It is relatively immobile within plant tissues. However, under certain conditions Fe is to some extent withdrawn prior to abscission (Sutcliffe and Baker 1974). Fe is one of the most plentiful elements in soil, yet almost all of it is immobile (Attiwill and Leeper 1987). The ferrous form (Fe^{2+}) is readily absorbed by plants but under alkaline conditions it is oxidised to the ferric form (Fe^{3+}) which is relatively unavailable (Sutcliffe and Baker 1974). Foliar Fe is positively correlated with exchangeable soil Ca, Mg and K and extractable P, but negatively correlated with organic C and pH (Herbert, 1991).

4.1.1.9 Manganese

Mn is a microelement where uptake is in the form of ions from the soil solution (Taiz and Zeiger 1991). Mn^{2+} is indispensable as a cofactor of the activity of many enzymes (Mohr and Schopfer 1995). Mn displays partial mobility within plant tissues (Sutcliffe and Baker 1974). Therefore, only moderate levels of Mn are retranslocated prior to litter fall. In well-aerated soils and at high pH, Mn^{2+} is oxidised to tri- or tetravalent ions which are absorbed less readily and for this reason sufficient Mn is often not readily available in calcareous soils (Sutcliffe and Baker 1974). Limited amounts of Mn are lost through volatilisation. The availability of Mn increases after the passage of fire; Grove et al. (1986) recorded a 12% increase in total Mn over pre-burn concentrations.

4.1.1.10 Sodium

Na is not formally a microelement but in certain instances (eg. for halophytes) it is regarded as such (Mohr and Schopfer 1995). Rainfall is the major source of Na addition to the nutrient budget. Na is highly mobile within plant tissues (Sutcliffe and Baker 1974). It is therefore retranslocated prior to litter fall and is susceptible to leaching from plant tissues. Uptake of Na is in the form of ions from the soil solution (Taiz and Zeiger 1991). A low pH is believed to reduce cation uptake by competition between hydrogen ions and the substrate cations for sites on a carrier (Sutcliffe and Baker 1974). The amount of exchangeable cations in forest soils follows the order Ca>Mg>K>Na (Attiwill and Leeper 1987). The total and extractable forms of Na increase significantly as a result of fire (Grove et al. 1986). Tomkins et al. (1991) reported that the more easily leached or utilised cations, such as Na^+, fall below pre-fire levels before recovering. Hall (1994) recorded losses of Na from a burnt plot at least twenty times greater than for the control plot.

4.1.1.11 Zinc

Zn is a microelement whose uptake is in the form of ions or chelates from the soil solution (Taiz and Zeiger 1991). Zn is relatively immobile within plant tissues (Sutcliffe and Baker 1974), therefore only limited amounts of Zn are remobilised upon leaf senescence. Foliar Zn is negatively correlated with exchangeable soil Ca, Mg and K and extractable P (Herbert 1991). Zn is strongly held by soil, although it may move a little at low pH (Attiwill and Leeper 1987). The transfer of Zn to the root may be limiting, due to its general immobility within the soil (Bowen 1981). The concentration of Zn within the soil increases after the passage of fire (Khanna et al. 1994). Zn is not highly susceptible to leaching from the soil due to its immobility.

4.1.1.12 Nitrogen

N is a macroelement where uptake is in the form of NO_3^- or NH_4^+ (Taiz and Zeiger 1991). N is contained in amino acids, nucleotides and macromolecules composed of them (proteins, DNA, RNA), and is a major component of enzymes, organelles and cytoplasmic membranes (Mohr and Schopfer 1995). N undergoes direct as well as indirect xylem to phloem transfer (Brown and Shelp 1997). N is withdrawn from leaves prior to abscission (Sutcliffe and Baker 1974) and is susceptible to losses in throughfall.

The total N content of Australian soils varies widely (Williams and Raupach 1983). One of the main sources of N entering the soil-plant system is rain (Groves 1983). N occurs as nitrate, nitrite, ammonium and free ammonia dissolved in the soil solution. N supply to plants can, in theory, be fulfilled by NH_4^+ uptake, whereby it is possible to save a considerable amount of metabolic energy. In practice, many species have a preference for NO_3^-. Large losses of N in non-particulate form are typical during vegetation fires, due to the low volatilisation temperature of N (Raison et al. 1985a). However, the availability of N is still increased within the soil (Tomkins et al. 1991). Elevated levels of N are short lived due to rapid immobilisation and leaching losses, Grove et al. (1986) recorded the return of ammonium and nitrate ions to pre-burn levels within six months.

4.2 MATERIALS AND METHODS

4.2.1 Sample preparation and analysis

Using a hot air gun to melt the binding resin, the persistent leaf bases of each individual colour band were extracted one by one from the stem. The leaf bases were stored in brown paper bags labelled with the date and the colour of the band. Hovex lacquer thinner (Pascoe's Pty Ltd, Welshpool, Perth) was used to remove the sticky resin from the leaf bases, as melting off the resin from each leaf base was too time consuming. The resin was removed as it was considered that it may contaminate the chemical analyses, or cause a blockage in the mill during grinding.

It was necessary to determine whether soaking the leaves in the lacquer thinner would have a chemical effect on the leaf bases. In order to determine whether this was the case a small scale experiment was conducted. Five samples of leaf bases spanning the period 1943 to 1945 from Stem 1 were each randomly divided into three equal sized groups of approximately 10 leaf bases. One group was cleaned using the lacquer thinner, the second using the hot air gun and the third was left with the resin intact. These three alternatively prepared samples were then cut, and the 1st and 5th cm lengths of the leaf bases were sent to be analysed. Therefore, a total of 30 samples was analysed for the concentrations of P, K, Ca, Mg, Na, S, B, Cu, Fe, Mn and Zn within this experiment. The nutrient analyses results and statistical outputs for this experiment have been included as Appendix 2. It was found by performing a one-way analysis of variance ($\propto = 0.05$) on the results that the chemical composition of the 1st cm lengths of the melted and lacquer cleaned prepared bases were not significantly different from each other. However, these two had significantly greater nutrient levels then the bases with the resin left on. Generally the 5th cm samples showed no significant difference between any of the preparations. This was attributed to the fact that the 1st cm section of the bases had a thicker coating of the resin. Therefore, it was concluded that the resin did in fact alter the chemical results and that the lacquer thinner was an appropriate chemical to use in its removal.

Once the leaf bases had been cleaned, they were cut up into 1 cm lengths using secateurs. The bases were reliably between 4 cm and 5 cm in length, resulting in five cut sections. The five sections of leaf base were stored in 100 mL plastic vials that were generally not completely filled. In order to determine the best lengths of the leaf bases to send, the first batch of 105 samples had all of the five, 1 cm sections analysed. From these results it was decided to send only the 1st cm section, as it showed the greatest annual variation, and the 5th cm section as it showed the greatest seasonal variation. Only the 1st cm section, the innermost length, and the 5th cm section, the outermost length, were sent away for analysis, in an attempt to minimise the already high costs involved in the analyses. See Appendix 3 for the raw data and some representative graphs for the five sections.

After cutting, the samples were ground using a Culatti electric mill, Model DCFH 48 (Glen Creston Pty Ltd., England) through a mesh size of 1 mm and delivered to the

Western Australian Government laboratories (Hay Street, East Perth) for analysis. They were analysed for P, K, Ca, Mg, Na, and S on a percentage dry weight basis (% db), and for B, Cu, Fe, Mn and Zn in mg/kg. The analytical method employed at the Government laboratories was called 'Determination of metals in plant material and feedstuffs (Method Code P02)'. The method uses concentrated nitric acid and perchloric acids to destroy organic matter in the sample, evaporation of the nitric acid, making to volume with deionised water and analysis by ICP-AES (inductively coupled plasma - atomic emission spectroscopy).

It was assumed that few trends would be observed for N, due to its high mobility and therefore natural variability and susceptibility to leaching losses. To be certain of this, a selection of 20 samples ranging from 1930/31 to 1940, and 20 samples from 1977/78 to 1988, both from the Gyngoorda stem, was analysed to determine if any trends existed.

4.2.2 Moisture content

It was necessary to determine the moisture content of the ground leaf base samples so that an accurate correction value to a dry weight basis could be applied to the results. Ten samples were left in a 60°C oven for 48 hours. A mean moisture content of 10% was determined and therefore applied to all the chemical analyses.

4.2.3 Statistics

The initial statistical test performed was a two-sided non-parametric runs test at a significance level of 0.05. This test was performed to determine whether the run of all raw data concentrations along the length of each stem displayed random variation (Zar 1996). Within this test the numbers of observations above K and below K were related to a normal approximation, K is equal to the mean of the raw data (Minitab Inc. 1991). If the run was random, the concentrations were not affected by external factors, if not, it is suggested that fire or season were influencing the nutrient levels. This test was employed as a precursor to the more powerful two-way analysis of variance. A two-way does not always pick out all trends within the data. However, you can be confident that any trends it identifies, do exist. The runs test gave an insight to the more subtle trends of variation within the data.

Chemical changes in the leaf bases running up the stem were statistically equated with annual growth cycles, the incidence of fires and nutrient uptake patterns after fire. Two-way analyses of variance were used, at a significance level of 0.05 to determine whether the nutrient contents of Stem 1 and Stem 2 at the time of fire differed significantly from those immediately, and in successive years, after a burn, and to identify any impact of season on nutrient content. Interaction effects were investigated by interpreting patterns of change within two dimensional sections of the response surface plots. The two-way treatments had uneven sample sizes as the inter-fire intervals along the length of the stems were highly variable. The maximum n value was 20 and the minimum was 7. Samples even further into the post-fire environment were available, but they were not included as their smaller number (3 to 5) would have introduced too much potential bias.

The means and standard errors for each fire treatment determined by the two-way analysis were presented graphically so that the pattern of change after fire could be interpreted easily. Pre-fire means were included within these graphs simply to aid in interpretation. They were not included within the two-way analysis of variance tests as years before and after the fire were the same, and this would have introduced bias. The results for Stem 3 were also included within these graphs so that comparisons with the effect of fire on the previous two stems could be made. An arbitrary starting point was assigned to Stem 3 as no fires were recorded along the section of stem analysed.

The nutrient concentrations within Stem 3 could not be tested with the two-way analysis approach as no fires had been recorded for 60 years, variations could only be related to a seasonal effect. Paired *t*-tests were performed on the nutrient concentrations within Stem 3, at a significance level of 0.05, in order to determine whether the nutrient concentrations in the winter/spring (dark brown) samples differed significantly from the corresponding summer/autumn (light brown) samples. It was made certain that all the assumptions of these tests held true for the data, by applying appropriate transformations where necessary.

4.2.4 Soil analyses

Three soil samples from each of the three sites were collected for analysis. The three soil samples were collected 1 m from the base of the *X. preissii* stems that were analysed in this study. The litter layer was scraped off using a trowel, a soil sample was then collected from the 0 - 100 mm horizon. Two other samples were then collected using the same method, but at 120° in opposite directions from the first sample.

While on site each soil sample was mixed in a bucket, sieved to remove large gravel particles and then stored in calico bags. On return to the laboratory, the samples were thoroughly re-mixed and stored in plastic vials. The samples were then dried at 60°C for 48 hours. The samples were analysed for P, K, ammonium, nitrate, pH (water), conductivity, pH ($CaCl_2$), organic C, reactive Fe, extractable S, B, EDTA trace elements (Cu, Zn, Mn and Fe) and exchangeable cations (Ca, Mg, Na, K) at the CSBP soil and plant analysis laboratory; the analysis method descriptions have been included as Appendix 4. The results were analysed using a one-way analysis of variance ($\propto = 0.05$) to determine whether the nutrient contents were significantly different between sites. If the ANOVA assumptions did not hold true, the data were transformed to ensure normality and homoscedasticity of variance.

4.3 RESULTS

Results for concentrations of 12 mineral nutrients in the remnant leaf bases are given here. Each nutrient is considered in turn, describing first the mean concentrations at 5 year intervals over 50 years or more (omitting values at the time of fire and the following season to minimise the effect of fire on any trends). However, the runs test, for identifying non-random fluctuations, included all data. Then follow the concentrations in the 1st and 5th cm sections at the time of fire, and for each successive half year period, up to 5.5 years post fire. All raw data from the chemical analyses are listed in Appendix 5.

4.3.1 Phosphorus

The leaf base concentrations of P did not reliably fluctuate above trace levels for both cm sections for all three stems. It was unusual to have a concentration above 0.01% db (or 0.1 g/kg), which was the limit of detection. Therefore no statistical analyses could be performed and the data have been omitted.

4.3.2 Calcium

4.3.2.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) was performed to determine whether variation in concentration of Ca in the 1st cm section through time was random. The test showed that the variation in Stem 2 was random, but it was not in Stems 1 and 3 (Table 4-1). This confirms that the variation in the data for Stems 1 and 3 is due to the influences of external factors. As it was postulated that these influences are season and/or the passage of fire they are examined in detail next.

Table 4-1. Non-parametric runs test ($\alpha = 0.05$) on the Ca concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	93	89	0.0007
Stem 2	49	53	0.0707
Stem 3	44	54	0.0007

The concentration of Ca within the 1st cm section of leaf bases from Stem 1 varied substantially over time (Figure 4-1). Little variation was seen in the leaf bases from Stems 2 and 3. The Stem 1 concentration of Ca peaked in the most recent leaf base samples (1985-90).

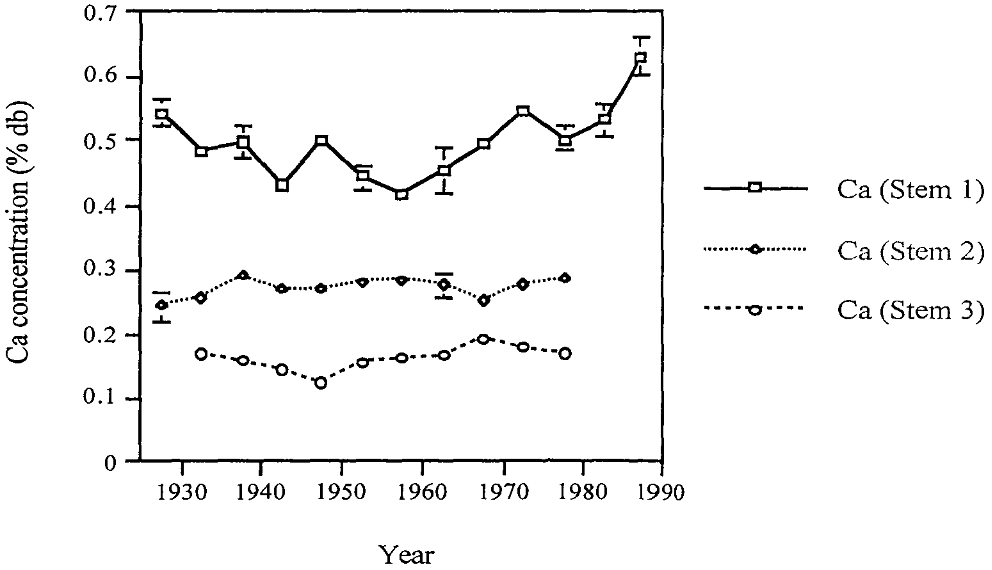

Figure 4-1. Five yearly mean Ca concentration (% db) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

The immediate effect of the passage of fire (black band, see Chapter 3) on Stem 1 was a drop in Ca concentration from pre-fire levels. Stem 2 did not show this immediate reaction (Figure 4-2). After the initial drop, Stem 1 demonstrated rapid uptake of Ca for the next few post-fire growing seasons. Elevated Ca concentrations were also recorded within the leaf bases of Stem 2. Ca concentrations within the leaf bases from Stem 1 and Stem 2 peaked at 2.5 years, and 3 years after fire, respectively. Stem 3 displays the pattern of Ca cycling when fire is excluded. Ca concentrations within this stem remain stable relative to the variation within Stems 1 and 2. A regular winter/spring peak in the Stem 3 Ca concentrations is discernible. The mean Ca contents of the Stem 1 leaf bases were consistently higher than those of Stem 2, which were both higher than those in Stem 3.

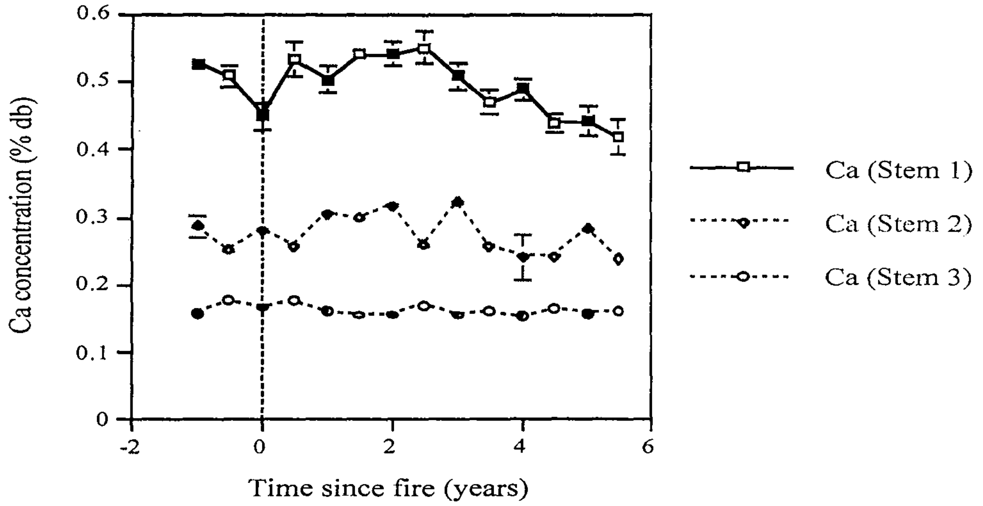

Figure 4-2. Mean Ca concentration in the 1st cm section of leaf bases from Stem 1, 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

Some seasonal variation in the concentrations of Ca existed within all 3 stems. The mean winter/spring concentration of Ca was higher than the summer/autumn concentration in the 1st cm section of leaf bases from Stem 1 and Stem 3. However, the summer/autumn concentration was higher in leaf bases from Stem 2.

A two-way analysis of variance was performed to determine whether the variation in the concentration of Ca in relation to fire and season was significant ($\alpha = 0.05$). Table 4-2 displays the summarised results of this analysis for Stem 1 (all statistical output has been included in Appendix 6). Fire had a highly significant effect on the concentration of Ca within the leaf bases of Stem 1. Stem 1 recorded no seasonal effect, although there was significant interaction. The mean winter/spring Ca concentration was greater than the mean summer/autumn concentration for 3 years after the fire, after which the summer/autumn concentration was greater for at least the next 3 years. The 1st cm section of leaf bases from the summer/autumn bands of Stem 1 had an overall mean Ca concentration of 0.49% db, compared with a winter/spring mean concentration of 0.51% db.

Table 4-2. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Ca within the 1st cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.7944
Time since fire	5	0.0003
Interaction	5	0.0211
Residual	144	

Table 4-3 displays the two-way analysis of variance results for the Ca concentration within the leaf bases of Stem 2. The analysis shows that there is a highly significant fire effect, season effect, and interaction between the two exists. The mean summer/autumn Ca concentration was greater than the mean winter/spring concentration throughout. However, 2 years and 5 years after the fire the difference between the two was minimal, indicating the location of the interaction effect. The mean 1st cm section summer/autumn concentration was 0.29% db and the winter/spring mean was 0.26% db for Stem 2.

Table 4-3. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Ca within the 1st cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0001
Time since fire	5	0.0001
Interaction	5	0.0255
Residual	42	

A paired *t*-test ($\alpha = 0.05$) was performed to determine whether the 1st cm winter/spring and summer/autumn concentrations were significantly different within Stem 3. A *P*-value of 0.002 was obtained. It was therefore concluded that the seasonal variation in Ca was indeed significant within Stem 3. The mean 1st cm section summer/autumn concentration was 0.16% db, and the winter/spring mean was 0.17% db. Therefore, the winter/spring concentration of Ca was significantly higher than the summer/autumn concentration within Stem 3. In contrast, it was found to be significantly lower within Stem 2. Although not statistically significant, the trend in Stem 1 supported the results from Stem 3, i.e. a higher winter/spring concentration.

4.3.2.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) was performed to test whether the variation in concentration of Ca within the 5th cm section of leaf bases was random through time (Table 4-4). The results for Stem 1 were found to display random variation. However, the sequential concentrations from Stem 2 and Stem 3 are not random.

Table 4-4. Non-parametric runs test ($\alpha = 0.05$) on the Ca concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	82	100	0.4432
Stem 2	51	51	0.0288
Stem 3	45	47	0.0064

The Ca concentration in the 5th cm section of leaf bases from Stem 1 did not display substantial variation due to the passage of fire. However, Stem 1 and Stem 3 did display distinct seasonal variation as seen in Figure 4-3. The winter/spring concentration of Ca was reliably higher than the corresponding summer/autumn concentration. The mean Ca concentrations of Stem 3 were greater than the concentrations within Stem 1, for the 5th cm section.

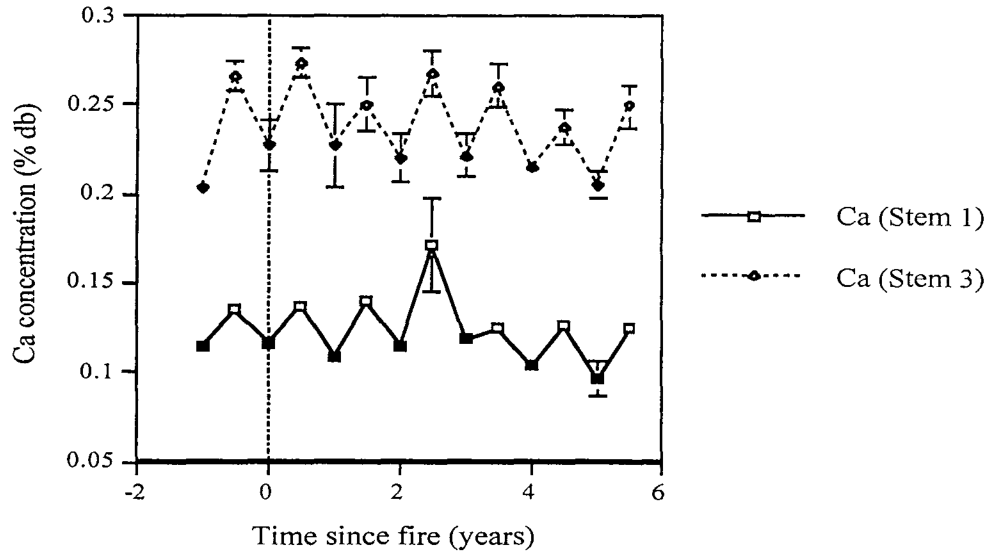

Figure 4-3. Mean Ca concentration in the 5th cm section of leaf bases from Stem 1 and Stem 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

Neither the fire effect nor seasonal variations were obvious within the 5th cm section of the leaf bases from Stem 2 (Figure 4-4). Little variation in the concentration of Ca existed throughout the 5th cm section of Stem 2, except the peak 4 years after fire which is accounted for by error.

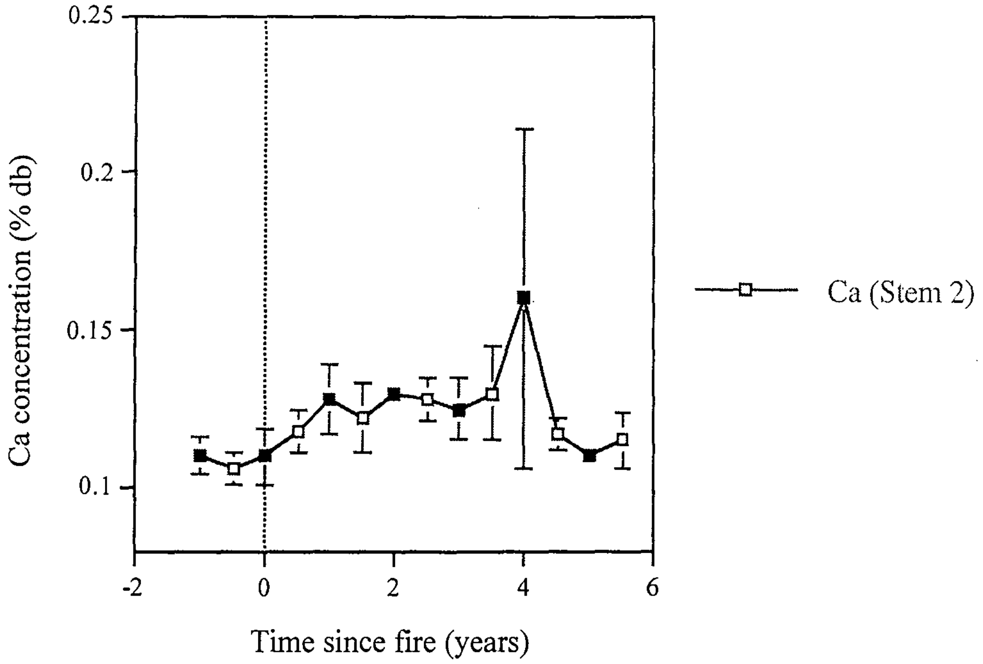

Figure 4-4. Mean Ca concentration in the 5th cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

The winter/spring concentrations of Ca were again higher than the summer/autumn concentrations in the 5th cm section of leaf bases from Stem 1 and Stem 3. The reverse was seen in the concentrations from Stem 2. However, the scale of difference between the seasons for Stem 1 and 3 is larger than that for Stem 2.

A two-way analysis of variance ($\alpha = 0.05$) was performed on the 5th cm concentrations of Stem 1 to determine any significant trends. The results have been summarised in Table 4-5, and have been included in Appendix 6. The seasonal effect was shown to be highly significant, the fire effect was insignificant and there was no interaction. The passage of fire had a negligible effect on the Ca concentration in the exterior length of the leaf base. The mean summer/autumn Ca concentration for Stem 1 was 0.11% db, and the mean winter/spring was 0.13% db.

Table 4-5. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Ca within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.0001
Time since fire	5	0.1228
Interaction	5	0.4347
Residual	144	

A two-way analysis was also performed on the 5th cm Ca concentrations from Stem 2. Both the fire effect and season effect were found to be insignificant, the test also showed that there was no interaction between the two. This result is due to the overall lack of variation within this sample. The mean Ca concentrations for the 5th cm sections of Stem 2 for summer/autumn and winter/spring were 0.19% db and 0.12% db, respectively.

A paired *t*-test ($\alpha = 0.05$) was performed to determine whether the winter/spring and summer/autumn concentrations were significantly different within Stem 3. For the 5th cm section, a *P*-value of 0.000 was calculated. It was therefore concluded that the seasonal variation in Ca was highly significant within Stem 3. The mean 5th cm section summer/autumn concentration was lower, 0.22% db, than the winter/spring mean of

0.26% db. Even though the opposite seasonal trend was again seen within Stem 2, the difference was determined to be insignificant. Therefore, the significant seasonal effect (Stem 1 and Stem 3), with a winter/spring maximum, is assumed to be the general trend.

4.3.3 Potassium

4.3.3.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) was performed to determine whether the sequential concentrations of K were random. It was concluded from the results for all 3 stems that the concentrations were not random. The summarised output is given in Table 4-6. This means that the variation in the K concentration along the length of the three stems is being influenced by external factors.

Table 4-6. Non-parametric runs test ($\alpha = 0.05$) on the K concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	57	125	0.0000
Stem 2	21	12	0.0001
Stem 3	48	50	0.0003

High overall variation in the concentration of K existed in Stem 1 and Stem 3 over time (Figure 4-5). However, little variation was seen within the 1st cm of leaf bases from Stem 2. The concentration of K increased since 1960 in Stem 2 and Stem 3, and noticeably since 1975 in Stem 1, peaking in the most recent years sampled. The concentration of K actually showed an overall increase in concentration over time for both Stem 1 and 2. The initial levels recorded in the 1890 period within Stem 1 were in the range 0.01 to 0.03% db, in the 1930's, 0.01 to 0.06% db, and in the 1980's, 0.03 to 0.16% db.

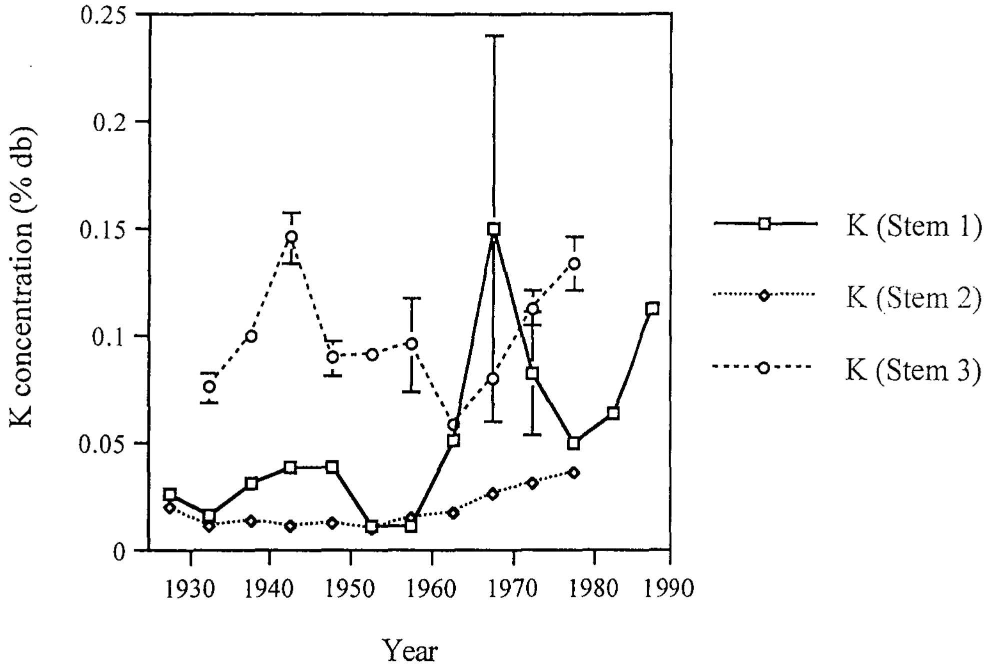

Figure 4-5. Five yearly mean K concentration (% db) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

There is a definite increase in K concentration within the 1st cm section of leaf bases from Stem 1 immediately after the passage of fire (Figure 4-6). There is no consistent variation in the K concentration of Stem 2 leaf bases in relation to the passage of fire or season, very limited variation existed at all. Stem 3 displayed sizeable seasonal variation with a summer/autumn maximum. The mean K concentrations of Stem 3 were higher than those within Stem 1. Stem 2 possessed the lowest means.

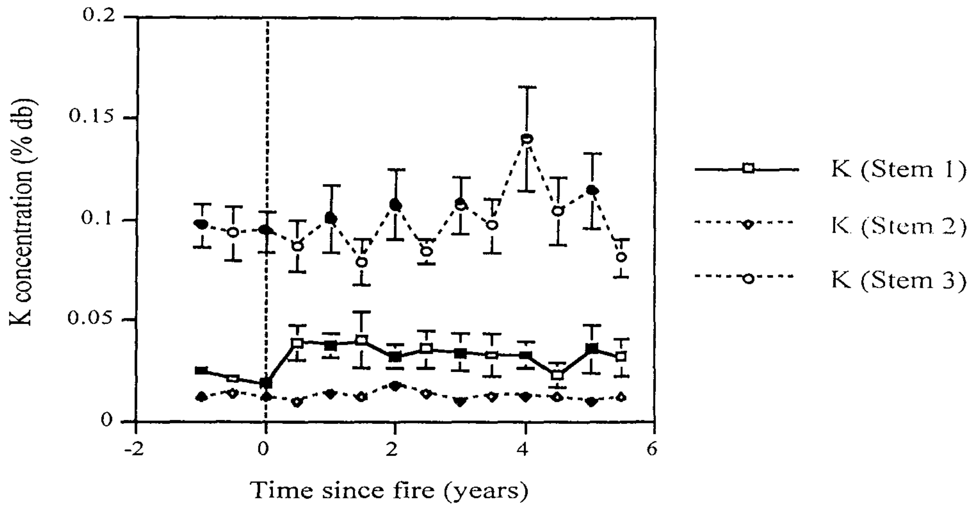

Figure 4-6. Mean K concentration in the 1st cm section of leaf bases from Stem 1, 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed to determine whether there were any significant effects of fire or season on K concentrations. It was concluded that fire and season had no significant effect on the K concentration in the 1st cm section of leaf bases from Stem 1, although there was significant interaction between the two (Table 4-7). The mean summer/autumn K concentrations were generally greater than the winter/spring means, except at the time of fire where the winter/spring concentration is greater, and 3 years and 6 years after the fire where the seasonal means are similar.

Table 4-7. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of K within the 1st cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.9685
Time since fire	5	0.8109
Interaction	5	0.0355
Residual	138	

No significant fire effect, season effect or interaction was recorded for the K concentration of the 1st cm sections of leaf bases from Stem 2. Random peaks and troughs were present throughout the data and are attributed to natural variation. Although no statistically significant fire effect on the concentration of K was recorded for both Stem 1 and 2, there is definitely a relationship. Figure 4-7 illustrates the effect of two fires on the K concentration in the 1st cm section of Stem 1. Distinct peaks in K were recorded immediately after the passage of both fires. Concentrations recovered to ambient levels within 2 years after fire.

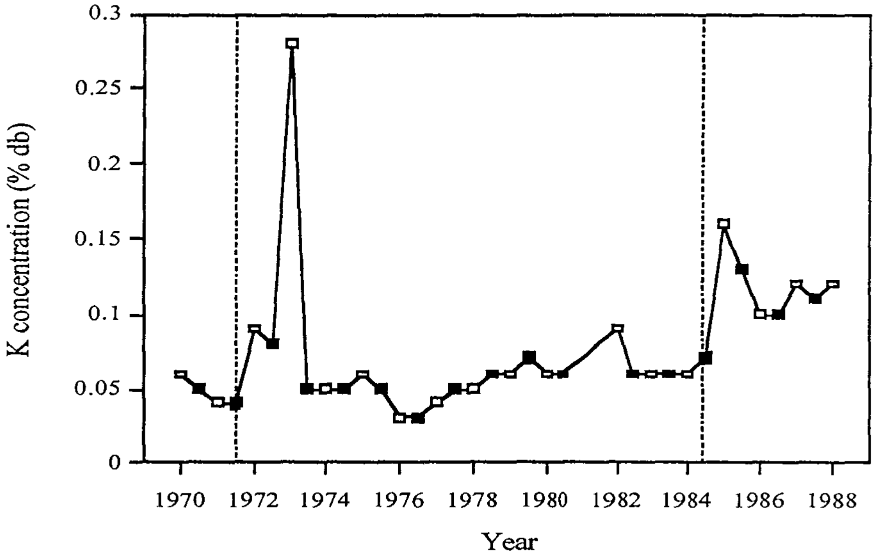

Figure 4-7. Changes in the K concentration in the 1st cm section of leaf bases from Stem 1 for the period winter/spring 1970 to winter/spring 1988. (The broken lines represent the time of the passage of fire, closed symbols are summer/autumn values, open symbols are winter/spring values.)

A paired *t*-test ($\alpha = 0.05$) was performed to determine whether there was significant seasonal variation within the 1st cm section of leaf bases from Stem 3. A *P*-value of 0.001 was calculated, indicating that there is seasonal variation in K within Stem 3. The summer/autumn concentration was 0.11% db, and the winter/spring concentration was 0.09% db, indicating a summer/autumn peak in assimilation for this stem. However the seasonal trends seen in the previous two stems contradict this: Stem 1 possessed a winter/spring peak in K, and Stem 2 recorded minimal seasonal differences.

4.3.3.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) concluded that the sequential 5th cm K concentrations for Stem 1 were not due to random variation, while the concentrations for Stem 2 were (Table 4-8). The analysis could not be performed on the results for Stem 3 as no variation in the low K concentrations was recorded.

Table 4-8. Non-parametric runs test ($\alpha = 0.05$) on the K concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	43	139	0.0000
Stem 2	8	10	0.1552
Stem 3	n/a	n/a	n/a

n/a - Test could not be completed as all values in the column were identical.

A distinct rise in the concentration of K immediately after the passage of fire was also recorded in the 5th cm section of the leaf bases from Stem 1 (Figure 4-8). Similar peaks in the K concentration were also recorded at 4 and 5.5 years after the passage of fire. However, the standard errors associated with these latter peaks are substantial. These peaks are due to the occurrence of an individual random outlier. The standard error of the immediate post-fire peak is small, suggesting a more consistent increase in the concentration of K. The K concentration within the 5th cm section of leaf bases from Stem 3 did not rise above 0.01% db.

No trends existed within the K concentrations of leaf bases from Stem 2 in relation to fire or season (Figure 4-9). The K concentrations were again very low within the 5th cm section of leaf bases from this stem.

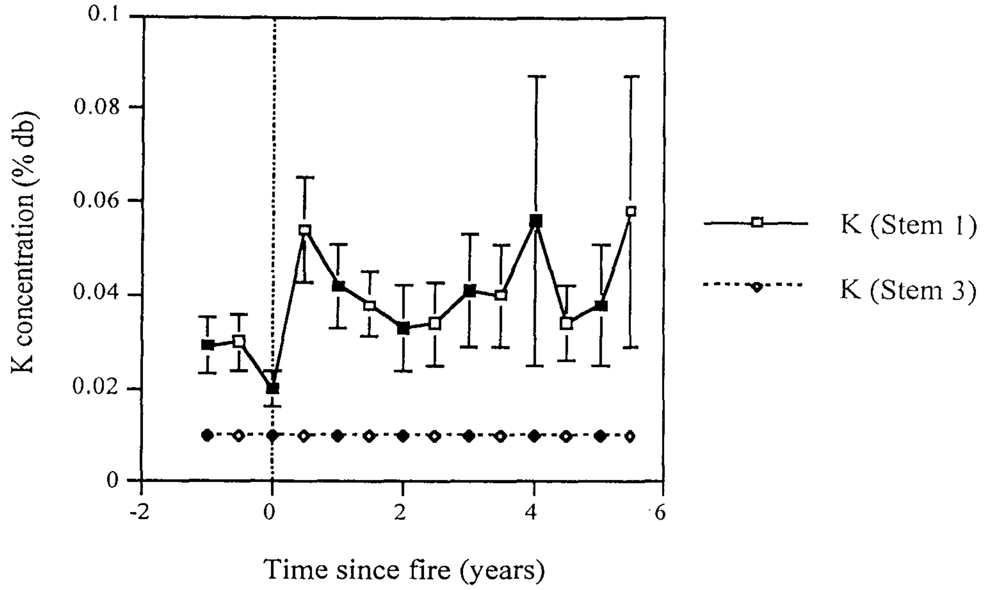

Figure 4-8. Mean K concentration in the 5th cm section of leaf bases from Stem 1 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

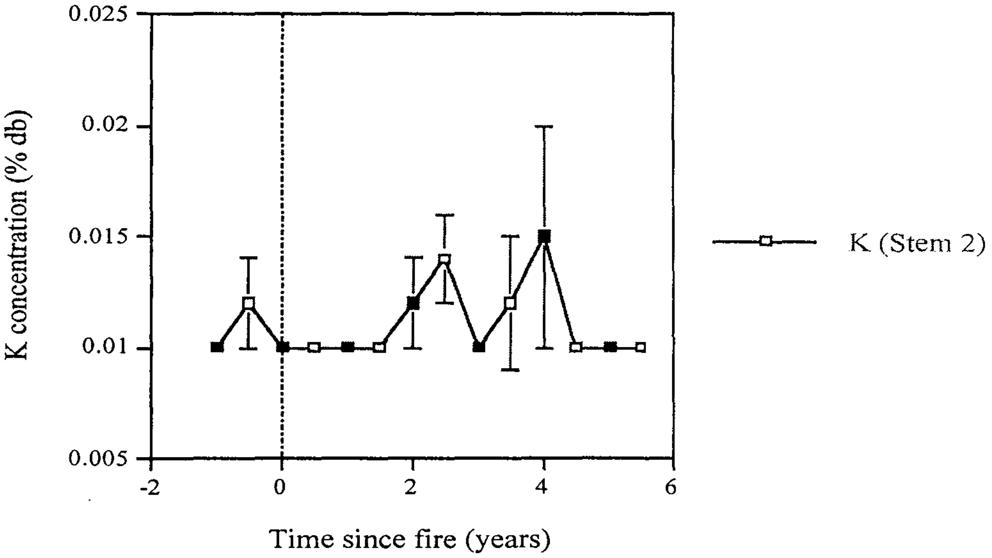

Figure 4-9. Mean K concentration in the 5th cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed to determine any statistically significant variation. Neither fire nor season had a significant effect on the K concentration of the 5th cm leaf base sections from Stem 1. No significant interaction between fire and season was recorded.

Very little variation in the K content of the 5th cm section of Stem 2 was recorded at all. The concentrations did not often rise above 0.01% db, which is very close to the minimum detection limit of the technique. A two-way analysis of variance ($\alpha = 0.05$) showed no significant fire effect, season effect or interaction within the 5th cm leaf base sections from Stem 2 .

A paired t-test could not be performed on the K concentrations of the Stem 3, 5th cm leaf base sections. The concentrations were again very low and did not fluctuate above 0.01% db. The standard error of the difference calculated by the paired t-test was 0; therefore the analysis could not be performed.

4.3.4 Magnesium

4.3.4.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) showed that the sequential Mg concentrations within the leaf bases from all three stems did not reflect random variation (Table 4-9). This suggests that the Mg concentrations are also being influenced by external factors.

Table 4-9. Non-parametric runs test ($\alpha = 0.05$) on the Mg concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	76	106	0.0000
Stem 2	45	57	0.0000
Stem 3	11	87	0.0043

The concentration of Mg in the 1st cm section of leaf bases along the length of both Stem 1 and Stem 2 was highly variable (Figure 4-10). Over time a slight decrease in Mg levels was revealed within Stem 1, whereas Stem 2 exhibited a definite increase. The concentration within Stem 3 remained relatively stable throughout the 45 year period sampled.

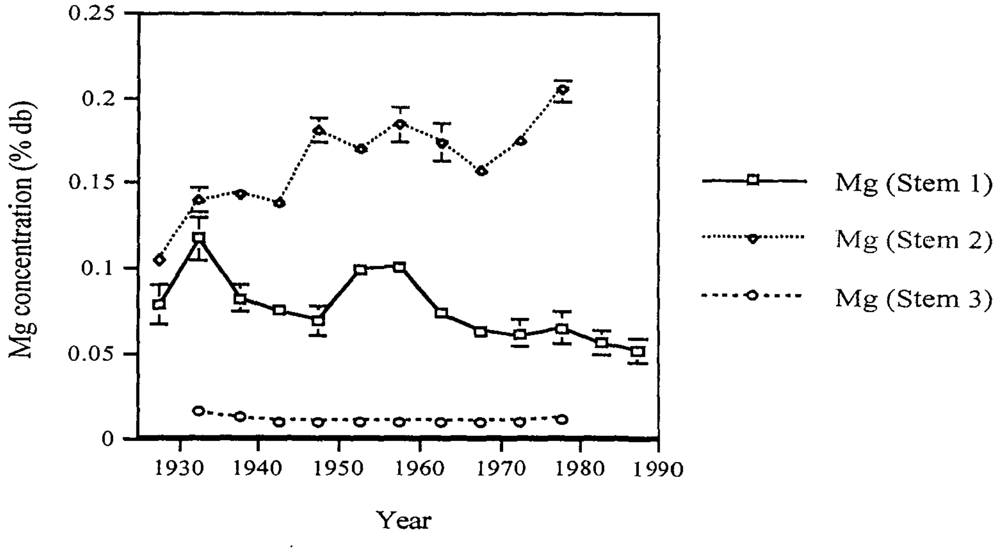

Figure 4-10. Five yearly mean Mg concentration (% db) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

The Mg concentration of the 1st cm leaf bases plummeted at the time of fire for Stem 2, and immediately after the passage of fire for Stem 1 (Figure 4-11). Mg began to recover to pre-fire levels after approximately 1.5 years had passed. Stem 3 displayed limited variation, accentuating the influence of fire on the Mg concentrations in Stem 1 and Stem 2. The concentration of Mg within the leaf bases of Stem 2 was consistently higher than those from Stem 1, which were both higher than Stem 3.

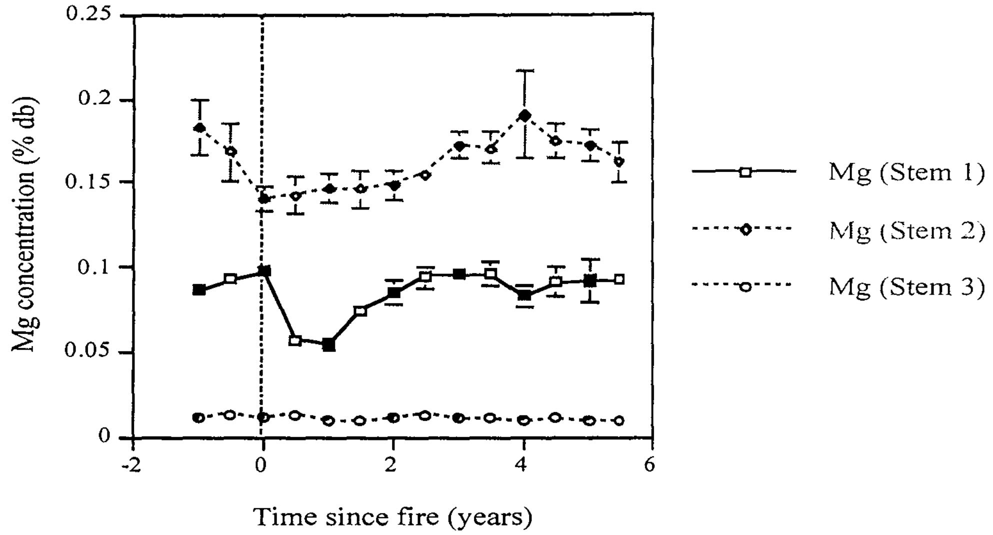

Figure 4-11. Mean Mg concentration in the 1st cm section of leaf bases from Stem 1, 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

The seasonal variation in the 1st cm section of leaf bases from Stem 1 was found to be insignificant by two-way analysis of variance (α = 0.05). However there was a significant fire effect and significant interaction between fire and season (Table 4-10). The mean winter/spring Mg concentrations were greater than the summer/autumn levels for all the post-fire years tested within the analysis of variance for Stem 1. However, at the time of fire, the summer/autumn concentration was significantly greater.

Table 4-10. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mg within the 1st cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.9086
Time since fire	5	0.0001
Interaction	5	0.0001
Residual	144	

The statistically insignificant season effect and significant fire effect found in Stem 1 are supported by the results from Stem 2 (Table 4-11). The interaction effect was however determined to be insignificant within Stem 2.

Table 4-11. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mg within the 1st cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.6239
Time since fire	5	0.0042
Interaction	5	0.9460
Residual	42	

There was no significant difference between the mean summer/autumn Mg concentrations and the winter/spring concentrations for both Stem 1 and 2. A paired *t*-test ($\alpha = 0.05$) was performed on the nutrient concentrations of the 1st cm section of leaf bases from Stem 3 to determine whether the seasonal effect was significant. A *P*-value of 0.252 was calculated, indicating that there is no significant seasonal variation in the Stem 3 samples.

4.3.4.2 5th cm section

The non-parametric runs test ($\alpha = 0.05$) showed that the Mg concentration data for the 5th cm section of leaf bases from Stems 2 and 3 show random variation (Table 4-12). However, it also indicated that the data for Stem 1 was not random, but determined by external factors.

Table 4-12. Non-parametric runs test ($\alpha = 0.05$) on the Mg concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	86	96	0.0000
Stem 2	46	56	0.2684
Stem 3	45	47	0.0945

Mg in the 5th cm section of leaf bases from Stem 1 dropped at the time of fire, reaching the lowest concentrations recorded for the entire stem (Figure 4-12). A uniform increase in the concentration of Mg was recorded in the leaf bases after the fire. Throughout this increase there is a consistent summer/autumn peak in Mg. The maximum Mg concentrations occurred 4 years after fire, with a return to ambient levels in successive years.

At the time of the passage of fire the 5th cm section of leaf bases from Stem 2 showed a small decrease in the concentration of Mg (Figure 4-13). After this initial drop, a sharp rise in Mg concentration occurred, peaking at 1.5 years since fire. Mg concentrations in the 5th cm section of leaf bases then began to return to pre-fire levels. Stem 3 clearly demonstrates regular seasonal variation.

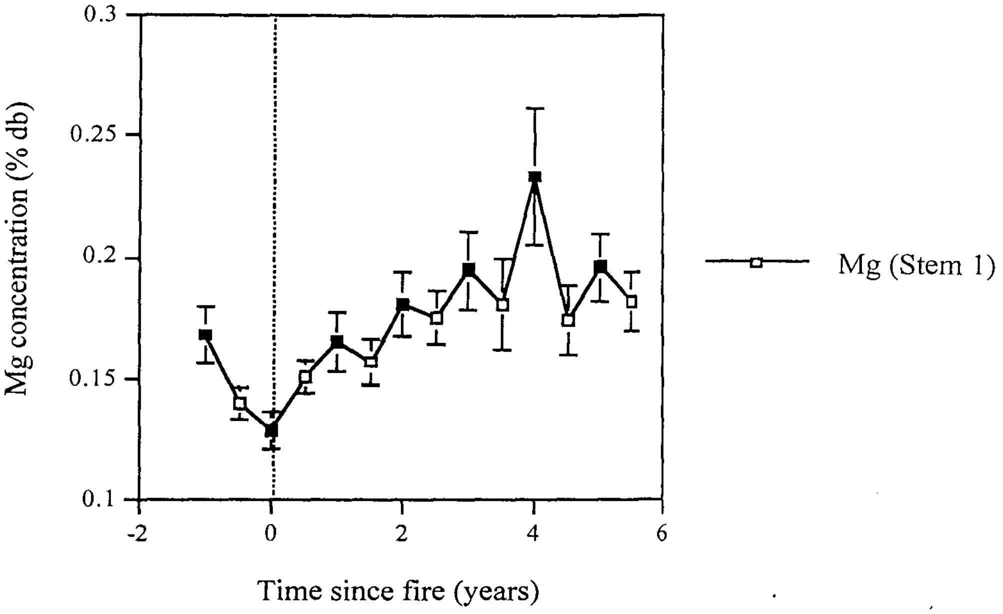

Figure 4-12. Mean Mg concentration in the 5th cm section of leaf bases from Stem 1 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

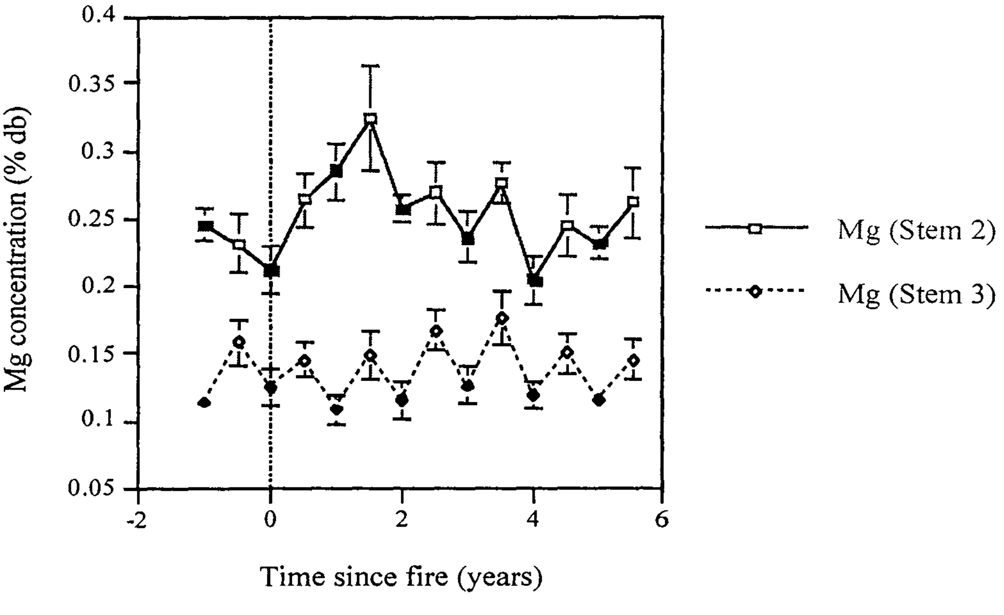

Figure 4-13. Mean Mg concentration in the 5th cm section of leaf bases from Stem 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed to determine the significance of the trends observed in the data, in relation to time since fire (years) and season. The results for this test are summarised in Table 4-13 and included in Appendix 6. It was concluded that within the 5th cm section of the leaf bases from Stem 1 there was no significant season effect or interaction, although there was a significant fire effect. It is important to note the insignificant season effect for this stem, as it possesses the opposite seasonal trend to that displayed within Stem 1 and Stem 2.

Table 4-13. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mg within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.1260
Time since fire	5	0.0001
Interaction	5	0.1280
Residual	144	

A two-way analysis of variance ($\alpha = 0.05$) performed on the Mg concentrations within the 5th cm section of leaf bases from Stem 2, indicated that there was a significant fire and season effect, and no interaction between them (Table 4-14). The season effect characterised by a winter/spring maximum is therefore statistically supported. A paired *t*-test ($\alpha = 0.05$) was performed on the nutrient concentrations of the 5th cm section of leaf bases from Stem 3. A *P*-value of 0.000 was calculated. This again supports a seasonal effect with a winter/spring peak in concentration.

Table 4-14. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mg within the 5th cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0104
Time since fire	5	0.0202
Interaction	5	0.9007
Residual	42	

4.3.5 Sulfur

4.3.5.1 1st cm section

The non-parametric runs test ($\alpha = 0.05$) indicated that the run of S concentrations for all 3 stems had distributions that could not be explained by random variation alone (Table 4-15). It is therefore likely that the concentrations are being influenced by other controlling factors.

Table 4-15. Non-parametric runs test ($\alpha = 0.05$) on the S concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	87	95	0.0000
Stem 2	58	44	0.0000
Stem 3	41	57	0.0000

The maximum concentrations of S were recorded in the youngest leaf bases sampled. Stem 3 showed a dramatic increase in S since 1945, as did Stem 1 since 1955 (Figure 4-14). The magnitude of increase within Stem 2 was lower, but a general upward trend existed.

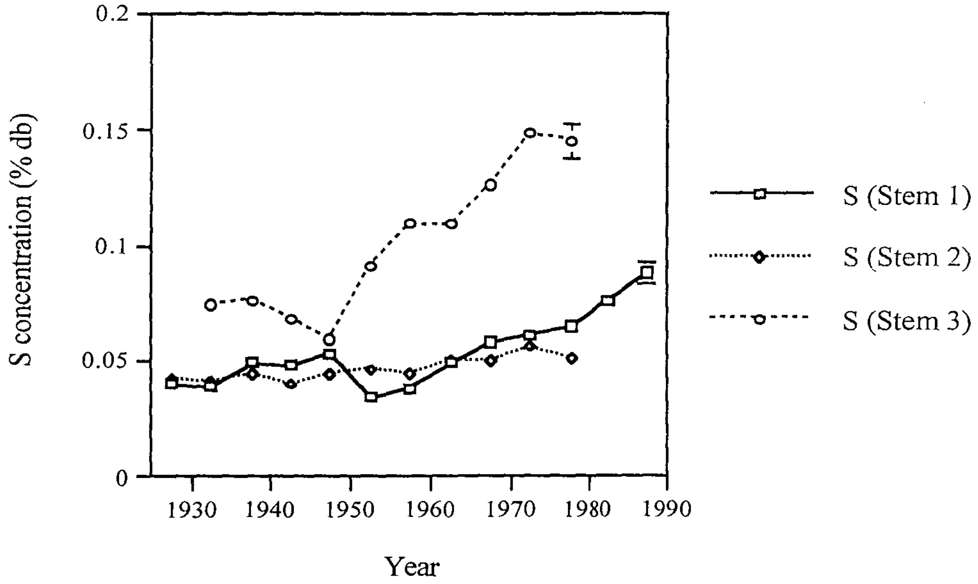

Figure 4-14. Five yearly mean S concentration (% db) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

The only effect of fire on the concentration of S within the 1st cm section of leaf bases from Stem 1 was a slight rise immediately after the passage of fire (Figure 4-15). The concentration returned to pre-fire levels within 1 year. Overall, little variation in the S content of leaf bases occurred within Stem 1. Stem 3 demonstrated a summer/autumn maximum in the concentration of S within the 1st cm section of its leaf bases.

Fire had no effect on the S content of leaf bases from Stem 2 (Figure 4-16). The concentration of S did not even waver from 1 year before the fire, when the fire passed through, to 1.5 years after the fire. After this period some variation in S was recorded.

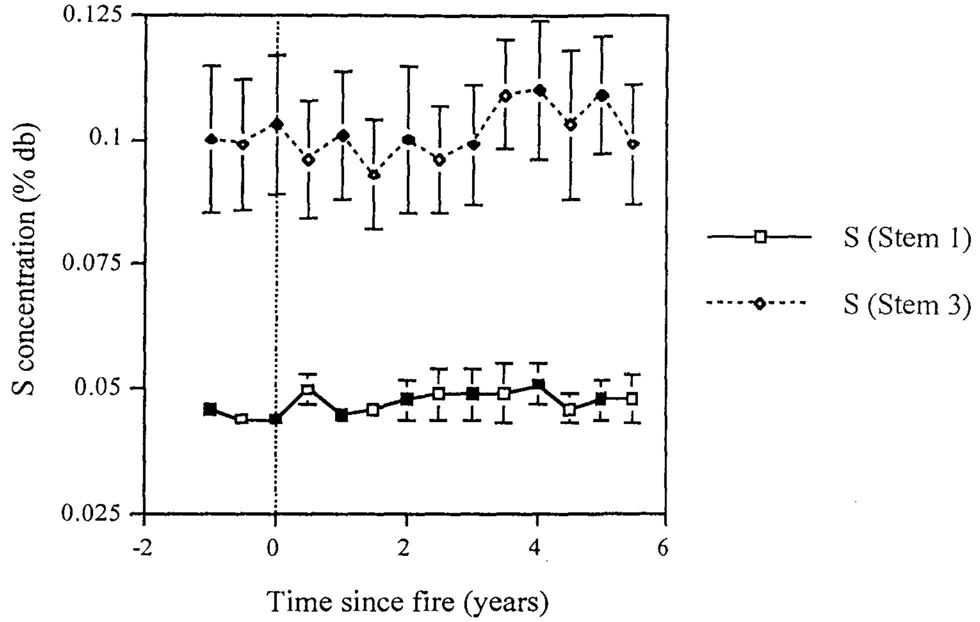

Figure 4-15. Mean S concentration in the 1st cm section of leaf bases from Stem 1 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

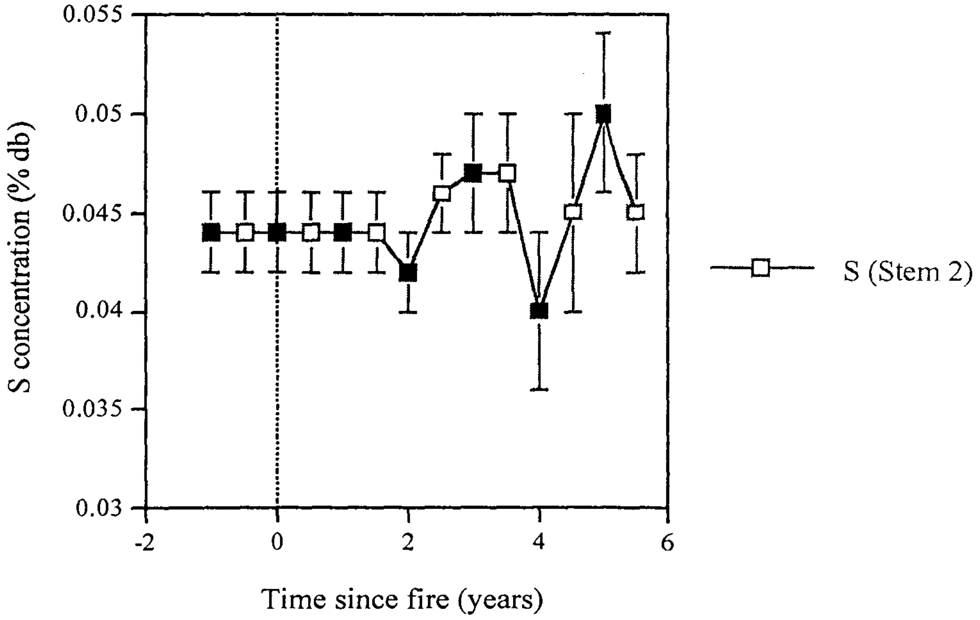

Figure 4-16. Mean S concentration in the 1st cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included.)

The results for both Stem 1 and Stem 2 were related to the passage of fire and season, through the implementation of a two-way analysis of variance ($\alpha = 0.05$). The P-values calculated were insignificant for all the fire and season comparisons, and for the interaction effect.

A paired t-test ($\alpha = 0.05$) indicated that there was a significant seasonal effect on the concentration of S within leaf bases of Stem 3 ($P = 0.017$). The mean summer/autumn S concentration was consistently higher than the winter/spring mean, with values of 0.103% db and 0.099% db, respectively.

4.3.5.2 5th cm section

The non-parametric runs test ($\alpha = 0.05$) gave a significant result for the 5th cm S concentrations for all three stems (Table 4-16). It was concluded that the sequential S concentrations did not display random variation.

Table 4-16. Non-parametric runs test ($\alpha = 0.05$) on the S concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	P
Stem 1	60	122	0.0000
Stem 2	25	77	0.0087
Stem 3	25	67	0.0000

Stem 1 displayed a peak in the concentration of S in the 5th cm section of its leaf bases at the time of fire (Figure 4-17). After this initial peak, S levels decreased for a few years; they then began to rise again, culminating in a lesser peak 4.5 years after fire.

Distinct seasonal variation with a summer/autumn peak was recorded for the S concentrations within the 5th cm leaf bases from Stem 3.

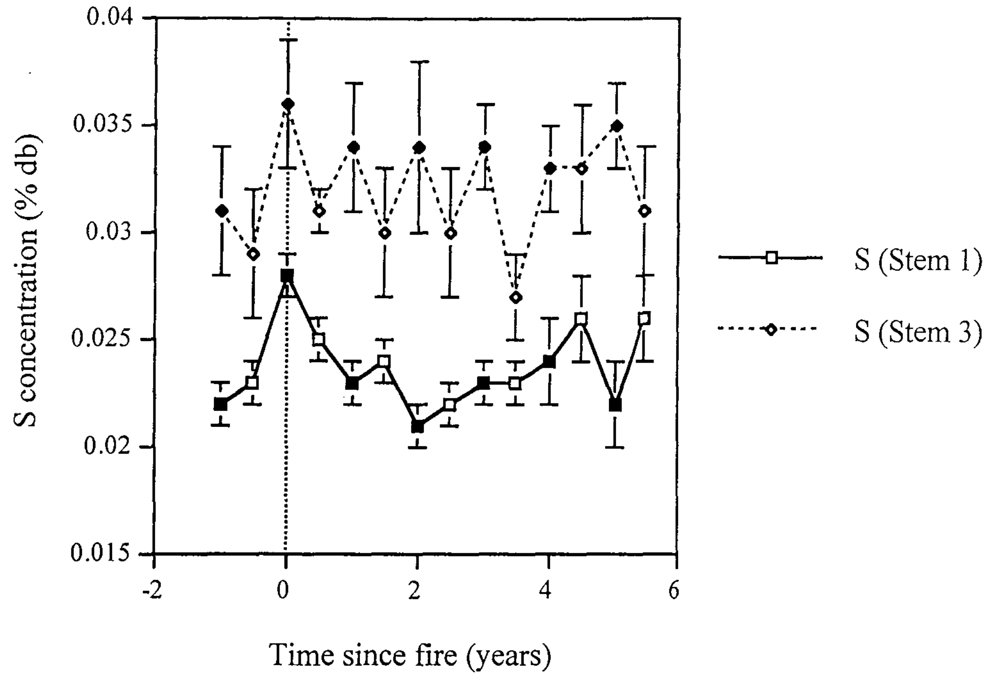

Figure 4-17. Mean S concentration in the 5th cm section of leaf bases from Stem 1 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

Stem 2 displayed only a slightly different trend to that mentioned previously for Stem 1. An increase in the concentration of S was recorded 0.5 years after the passage of fire. After this rise the same trend seen in Stem 1 is repeated in Stem 2. S concentration dropped slightly and then peaked again 4 years after fire. In this case, the second peak was the largest.

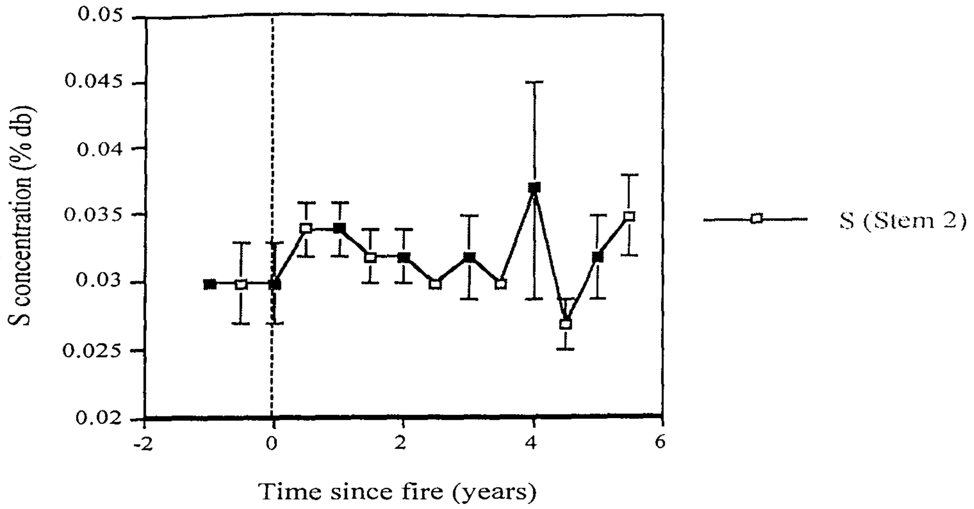

Figure 4-18. Mean S concentration in the 5th cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed on the 5th cm section S concentration results, from both Stem 1 and Stem 2, to determine the effects of fire and season. The test indicated that there was a significant fire effect on the S concentration of leaf bases from Stem 1. Neither season nor the interaction effect were significant within Stem 1 (Table 4-17). Insignificant probabilities were calculated for all effects within the two-way analysis of variance comparison ($\alpha = 0.05$) performed on the Stem 2 results and the results have been omitted.

Table 4-17. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of S within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.3767
Time since fire	5	0.0019
Interaction	5	0.2718
Residual	144	

A paired *t*-test ($\alpha = 0.05$) was performed on the results from Stem 3 to determine whether there was a significant seasonal effect. A *P*-value of 0.000 was calculated, indicating that the summer/autumn mean was significantly greater than the winter/spring mean.

4.3.6 Boron

4.3.6.1 1st cm section

The sequential B concentrations within all 3 stems were determined to be non-random. This conclusion was drawn from the results of a non-parametric runs tests ($\alpha = 0.05$) which are presented in Table 4-18.

Table 4-18. Non-parametric runs test ($\alpha = 0.05$) on the B concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	65	117	0.0000
Stem 2	88	14	0.0287
Stem 3	45	53	0.0000

The concentration of B in the 1st cm section of leaf bases from Stem 1 has increased sharply since 1950 (Figure 4-19). Stem 3 also demonstrated a distinct increase since 1945, while the gradient of increase within Stem 2 was a lot lower than Stems 1 and 3.

Immediately after the passage of fire a distinct rise in the concentration of B within the 1st cm section of leaf bases from Stem 1 was observed (Figure 4-20). Levels of B

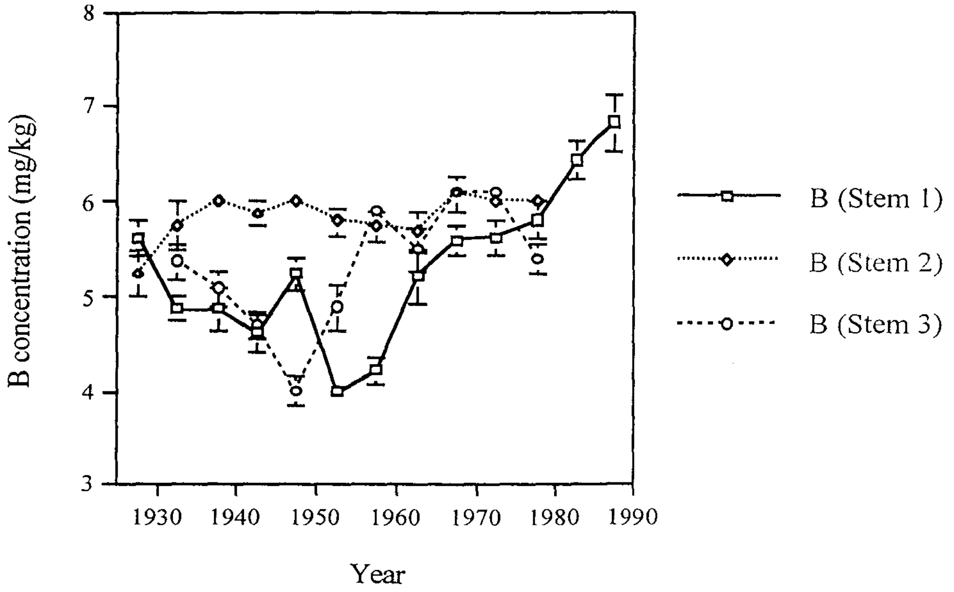

Figure 4-19. Five yearly mean B concentration (mg/kg) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

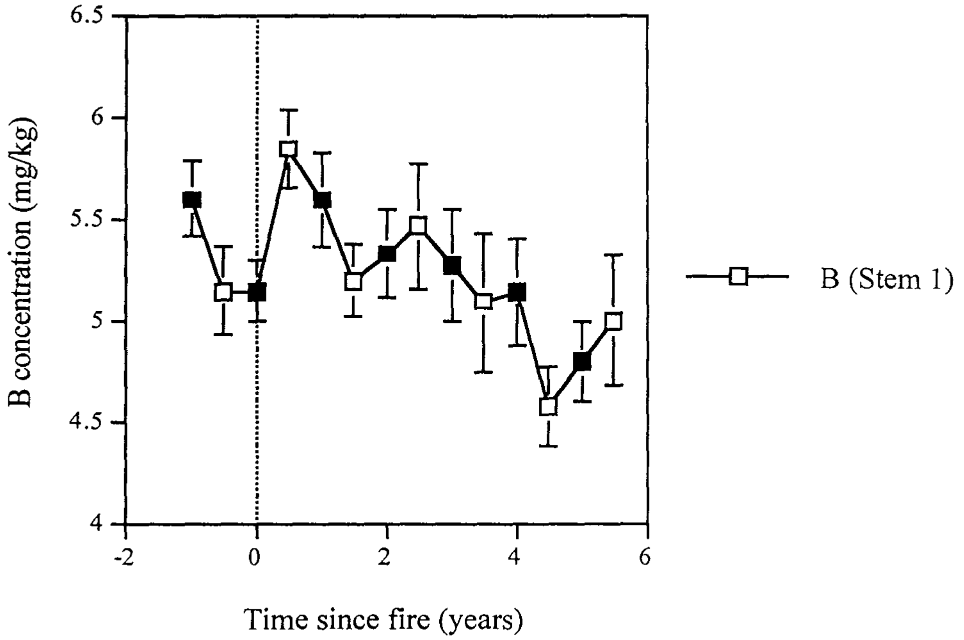

Figure 4-20. Mean B concentration in the 1st cm section of leaf bases from Stem 1 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Negative standard error bars have been included.)

decreased for 4 years after this initial peak, after which they began to return to pre-fire levels.

Stem 2 displayed little change in the concentration of B during and immediately after the passage of fire (Figure 4-21). However, a large decrease in B was recorded 4 years later, similar to when the minimum concentration was reached in Stem 1. Variation in the concentration of B within the 1st cm section of leaf bases from Stem 3 was irregular.

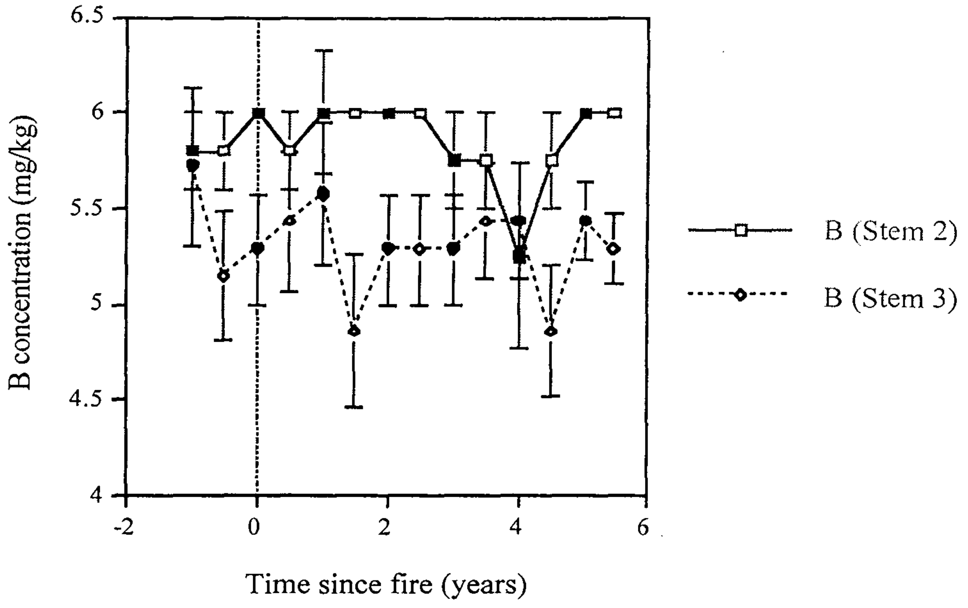

Figure 4-21. Mean B concentration in the 1st cm section of leaf bases from Stem 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) determined that no significant effects from fire, season or interaction, were present in the B concentration data for 1st cm leaf base sections from Stem 1 and Stem 2.

The summer/autumn concentration of B in the 1st cm section was greater than the winter/spring concentration for all three stems, yet the difference was not significant within Stems 1 and 2. For Stem 3, a paired *t*-test ($\alpha = 0.05$) indicated that the mean summer/autumn B concentration of 5.43 mg/kg was significantly greater than the winter/spring mean of 5.18 mg/kg ($P = 0.013$).

4.3.6.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) was performed on the B concentration of the 5th cm section of leaf bases from Stems 1, 2 and 3. It was concluded from the test results that the sequential data for all three stems does not exhibit randomness (Table 4-19).

Table 4-19. Non-parametric runs test ($\alpha = 0.05$) on the B concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	60	122	0.0000
Stem 2	18	84	0.0003
Stem 3	54	38	0.0065

The B concentration of the 5th cm section of leaf bases from Stem 1 plummeted at the time of fire (Figure 4-22). The concentration had recovered to pre-fire levels within half a year after the passage of fire. A winter/spring peak in the concentration of B is apparent within Figure 4-22.

B concentration displayed a very limited reaction to the passage of fire within the 5th cm section of leaf bases from Stem 2 (Figure 4-23). Minimal variation in the concentration of B existed throughout the length of Stem 2. No consistent variation was seen in the concentration of B within the 5th cm section of leaf bases from Stem 3.

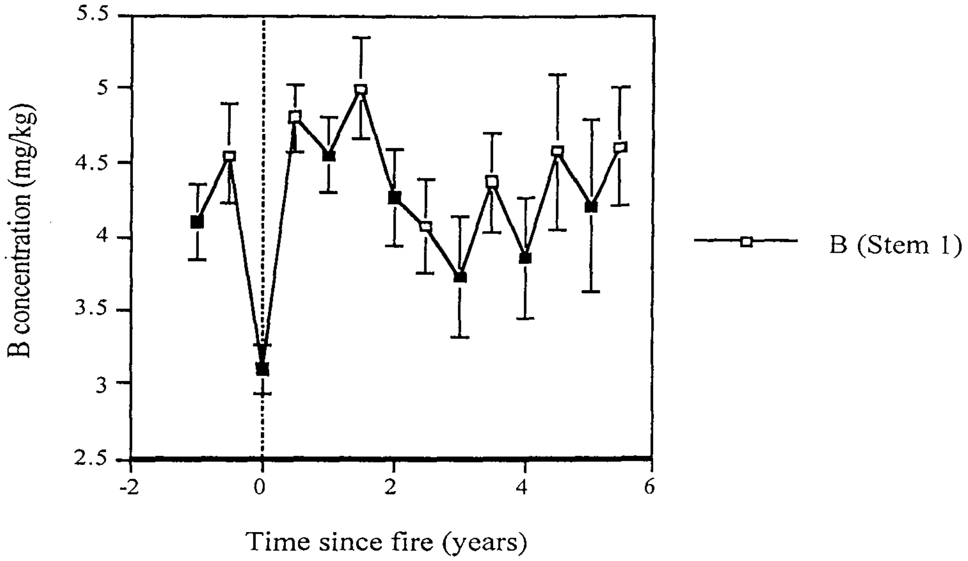

Figure 4-22. Mean B concentration in the 5th cm section of leaf bases from Stem 1 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

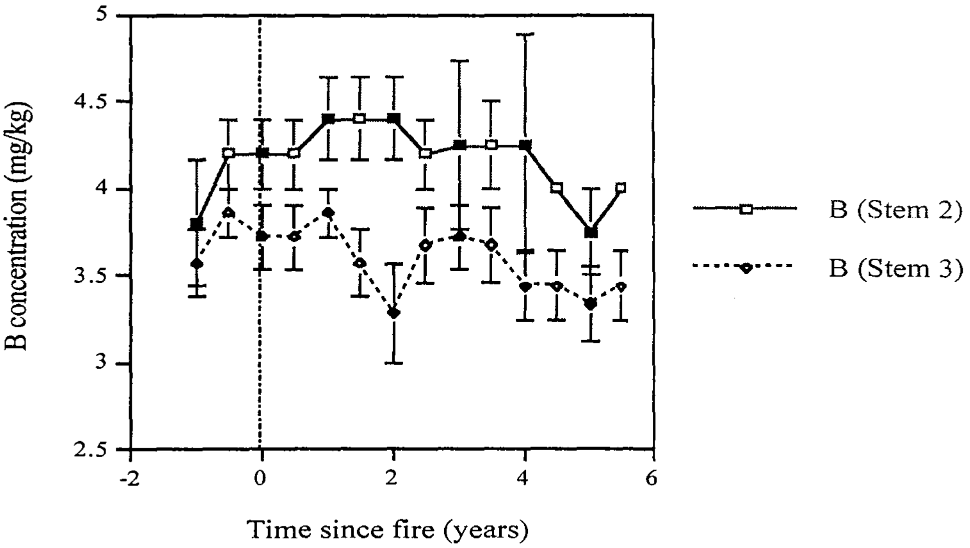

Figure 4-23. Mean B concentration in the 5th cm section of leaf bases from Stem 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed on the B concentrations of the 5th cm section of leaf bases from Stem 1. It was determined from the analysis that there is a significant season effect, insignificant fire effect and significant interaction between the two (Table 4-20). The mean winter/spring concentrations of B were generally greater than the summer/autumn concentrations for the post-fire period analysed. The only exception occurred 3 years after the passage of fire, when the winter/spring mean dips slightly below the summer/autumn mean. All of the comparisons for the 5th cm section of leaf bases from Stem 2 were insignificant.

Table 4-20. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of B within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.0051
Time since fire	5	0.0516
Interaction	5	0.0398
Residual	144	

A paired *t*-test ($\alpha = 0.05$) was performed on the B concentration results for Stem 3. The calculated *P*-value was 0.445, indicating that there was no significant difference between the mean seasonal B concentrations within Stem 3.

4.3.7 Copper

4.3.7.1 1st cm section

The non-parametric runs test ($\alpha = 0.05$) indicated that the sequential concentrations of Cu along the lengths of Stem 2 and Stem 3 were random. However, the concentrations along Stem 1 were not (Table 4-21).

Table 4-21. Non-parametric runs test ($\alpha = 0.05$) on the Cu concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	62	120	0.0011
Stem 2	31	71	0.7852
Stem 3	27	71	0.4260

The concentration of Cu within the 1st cm section of leaf bases from Stem 1 and Stem 2 displayed limited variation over time (Figure 4-24). However, the concentration within Stem 3 was highly variable. The Cu concentrations within Stem 3 were higher within the more recent 1955-1975 period then the 1930-1955 period. The maximum Cu concentration within Stem 1 was recorded in the youngest leaf bases sampled.

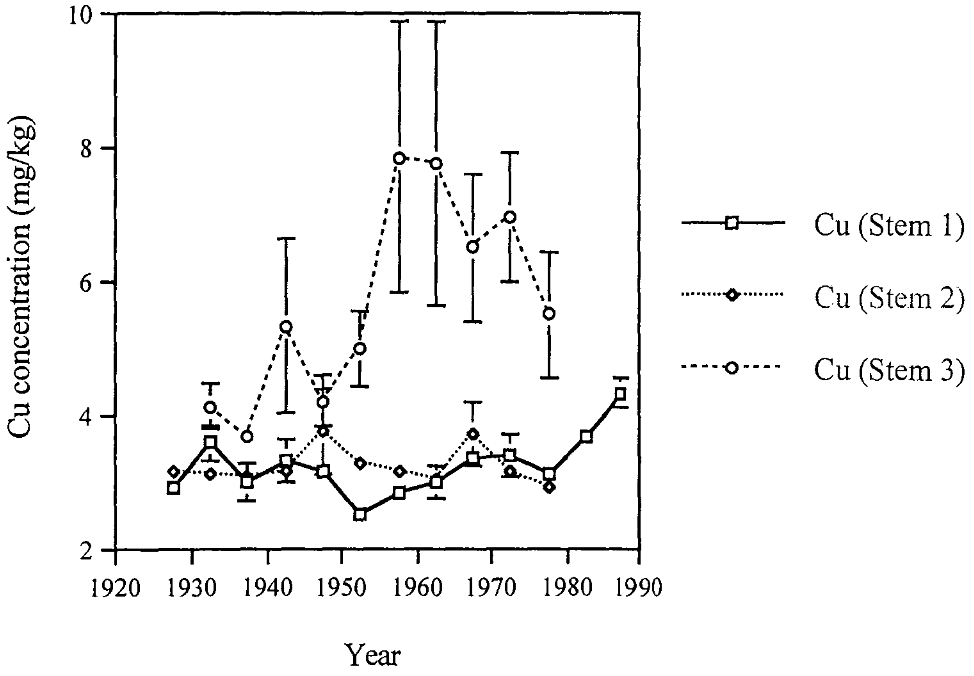

Figure 4-24. Five yearly mean Cu concentration (mg/kg) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

At the time of fire, a low concentration of Cu was recorded within the 1st cm section of leaf bases from Stem 1 (Figure 4-25). Directly after the passage of fire a sharp increase in Cu occurred, followed by a slow return to pre-fire levels. Stem 3 exhibited large scale variation in Cu along its length, no trends were apparent.

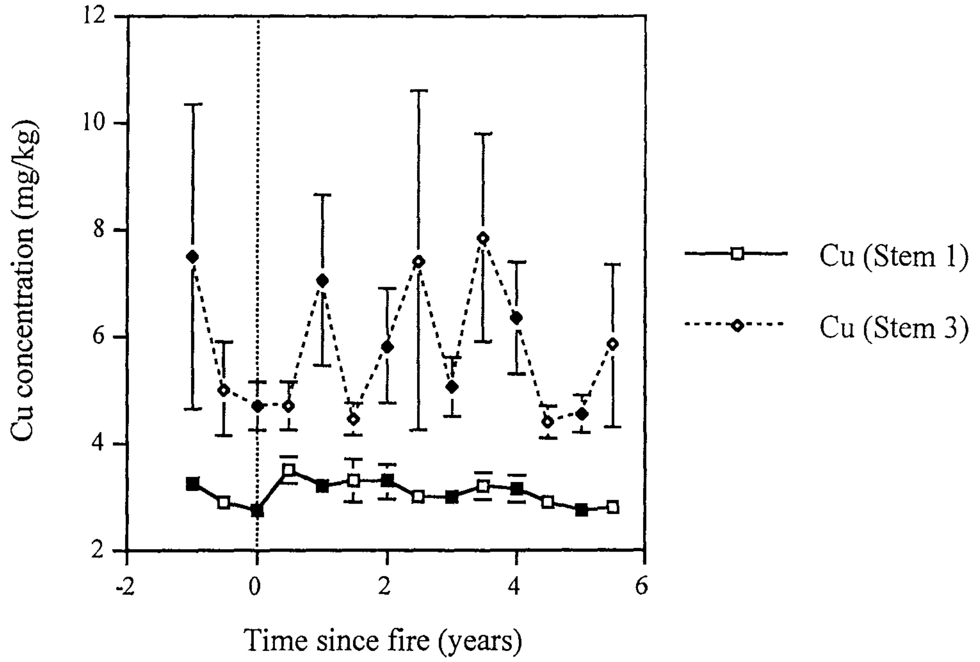

Figure 4-25. Mean Cu concentration in the 1st cm section of leaf bases from Stem 1 and Stem 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

No definite response to the occurrence of fire was seen in the Cu concentration of the 1st cm leaf bases from Stem 2. The only anomaly within Figure 4-26 is the distinct peak that occurs 4.5 years after fire. This peak is due to a large random outlier within the data, as supported by the large error bars it possesses.

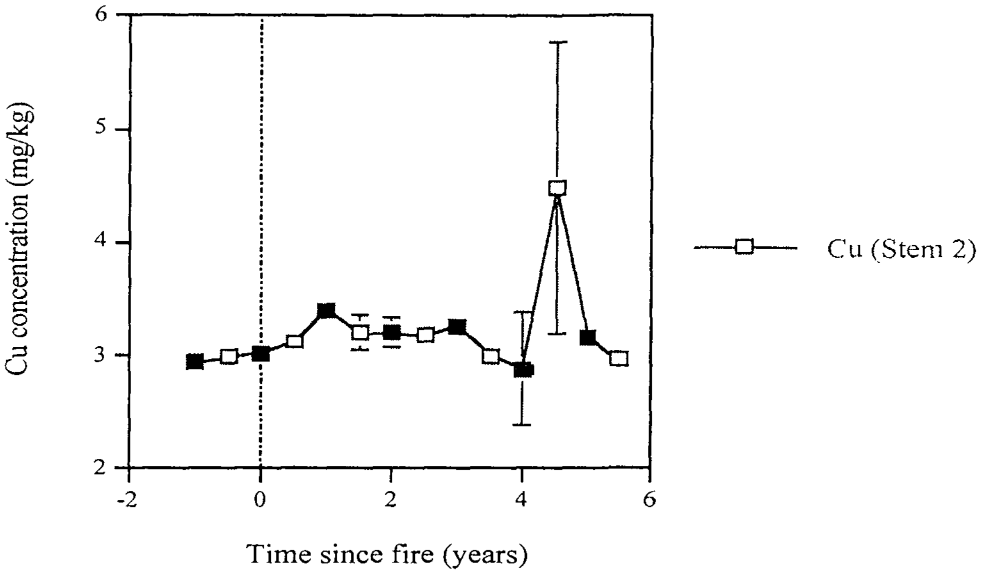

Figure 4-26. Mean Cu concentration in the 1st cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) showed no significant trends in the Cu concentrations of Stem 1 in relation to fire, season or the interaction between the two effects. No significant fire, season or interaction effect existed in the Cu concentrations from Stem 2 either.

No general trend was evident in seasonal variation for Cu concentration of the 1st cm section, due to contradictions between stems. A paired *t*-test ($\alpha = 0.05$) performed on the mean Cu concentrations in the 1st cm of leaf bases from Stem 3 again indicated no significant difference between seasons ($P = 0.807$). Therefore, season had no significant effect on the Cu concentration within the 1st cm section of any of the three stems.

4.3.7.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) was performed on the Cu concentrations for the 5th cm section from all three stems. The test showed that the concentrations from Stem 1 and Stem 3 were random data sets, however, concentrations from Stem 2 were not (Table 4-22).

Table 4-22. Non-parametric runs test ($\alpha = 0.05$) on the Cu concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	73	109	0.3192
Stem 2	49	53	0.0275
Stem 3	30	62	0.5401

A peak in the concentration of Cu occurred at the time of fire in the 5th cm section of leaf bases from Stem 1. After this peak, a decrease in Cu occurred for 2 years, after which the concentration stabilised, returning to natural variation levels. No seasonal effect is apparent within Figure 4-27.

The passage of fire appears to have a limited effect on the concentration of Cu within the 5th cm section of leaf bases from Stem 2. A seasonal effect, with a summer/autumn maximum, is obvious within both Stem 2 and Stem 3 (Figure 4-28). The cause of the Stem 2 peak in Cu concentration 4 years after the fire is unknown - it is most likely the result of random variation.

The results suggest that the summer/autumn concentration of Cu is generally higher than the winter/spring concentration within the 5th cm section of leaf bases. Stem 1

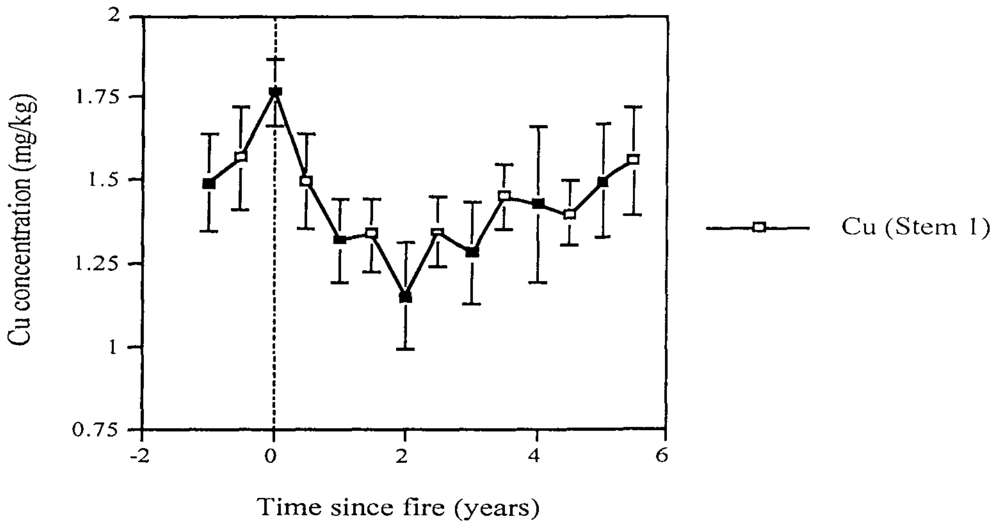

Figure 4-27. Mean Cu concentration in the 5th cm section of leaf bases from Stem 1 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

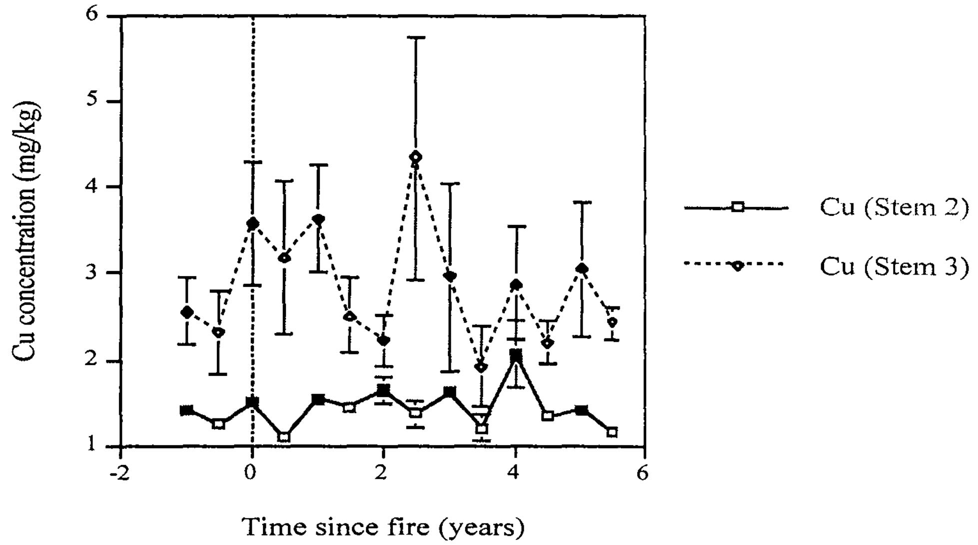

Figure 4-28. Mean Cu concentration in the 5th cm section of leaf bases from Stem 2 and Stem 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

displays the opposite trend, but due to the small scale of differences between the seasons in this example, and the large scale of difference in the latter two stems, the validity of the trend is questionable. Similar scales of difference between the seasons were seen in Stem 2 and Stem 3, with the summer/autumn level around 0.3 mg/kg greater.

A two-way analysis of variance ($\alpha = 0.05$) showed that there was an insignificant seasonal effect, and a significant effect of fire, on the Cu concentration within the 5th cm section of leaf bases from Stem 1 (Table 4-23). There was also a significant level of interaction between the two variables. The summer/winter concentration of Cu was greater than the winter/spring concentration in the first year after the passage of fire. Little difference between the seasonal means was seen in the second post fire year, after which the winter/spring means were consistently greater, for the successive four post-fire years analysed.

Table 4-23. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Cu within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.2931
Time since fire	5	0.0025
Interaction	5	0.0314
Residual	144	

Fire and season had a significant effect on the Cu content of the 5th cm section of leaf bases from Stem 2. The summarised results from the two-way analysis of variance ($\alpha = 0.05$) are presented in Table 4-24. There was an insignificant level of interaction between season and fire.

Table 4-24. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Cu within the 5th cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0001
Time since fire	5	0.0431
Interaction	5	0.4726
Residual	42	

A paired *t*-test ($\alpha = 0.05$) was performed on the Cu concentrations of the 5th cm section of leaf bases from Stem 3 to determine whether there was a significant seasonal effect. A *P*-value of 0.392 was calculated in the analysis, indicating an insignificant seasonal effect.

4.3.8 Iron

4.3.8.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) was performed on the sequential Fe concentrations in the 1st cm section of leaf bases from all 3 stems. The Fe concentration data from Stem 2 exhibited randomness, while the data from Stems 1 and 3 did not (Table 4-25).

Table 4-25. Non-parametric runs test ($\alpha = 0.05$) on the Fe concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	56	126	0.0183
Stem 2	22	80	0.2999
Stem 3	24	74	0.0000

No pattern of variation in the concentration of Fe was displayed in the 1st cm section of leaf bases from Stems 1, 2 nor 3 over time. Large random outliers occurred within both Stem 1 and Stem 2 (Figure 4-29). The concentrations of Fe within leaf bases from Stem 3 were very low; they did not reliably fluctuate above the limit of detection which was 10 mg/kg.

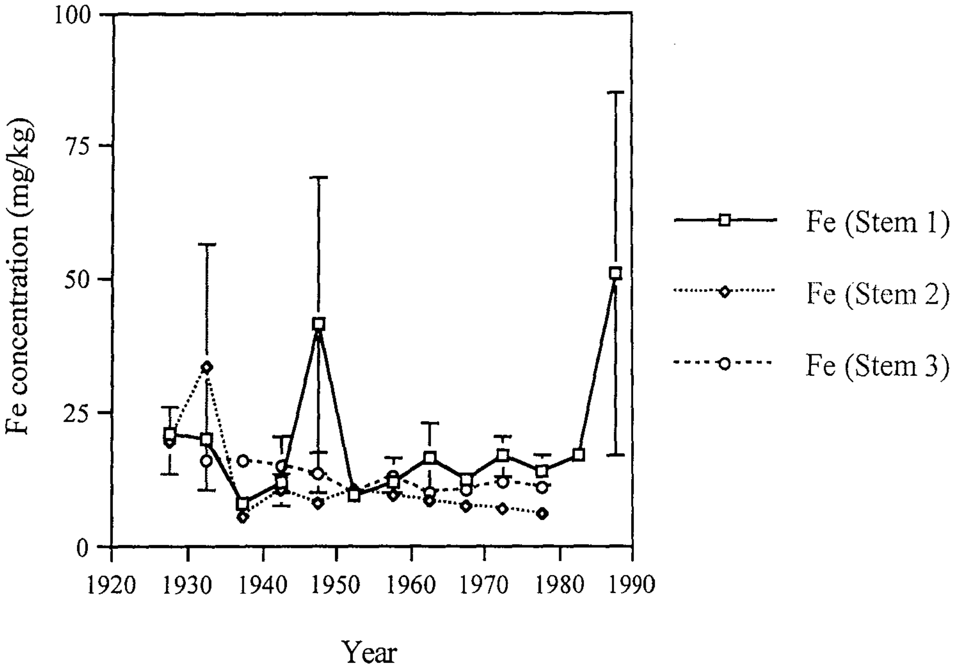

Figure 4-29. Five yearly mean Fe concentration (mg/kg) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

No trends existed in the concentration of Fe within the 1st cm section of leaf bases from either Stem 1 or Stem 2 in relation to fire (Figure 4-30). A winter/spring maximum in Fe concentration is just discernible within Stem 1. A number of random peaks and troughs were present throughout the Fe concentration data and are attributed to natural variation.

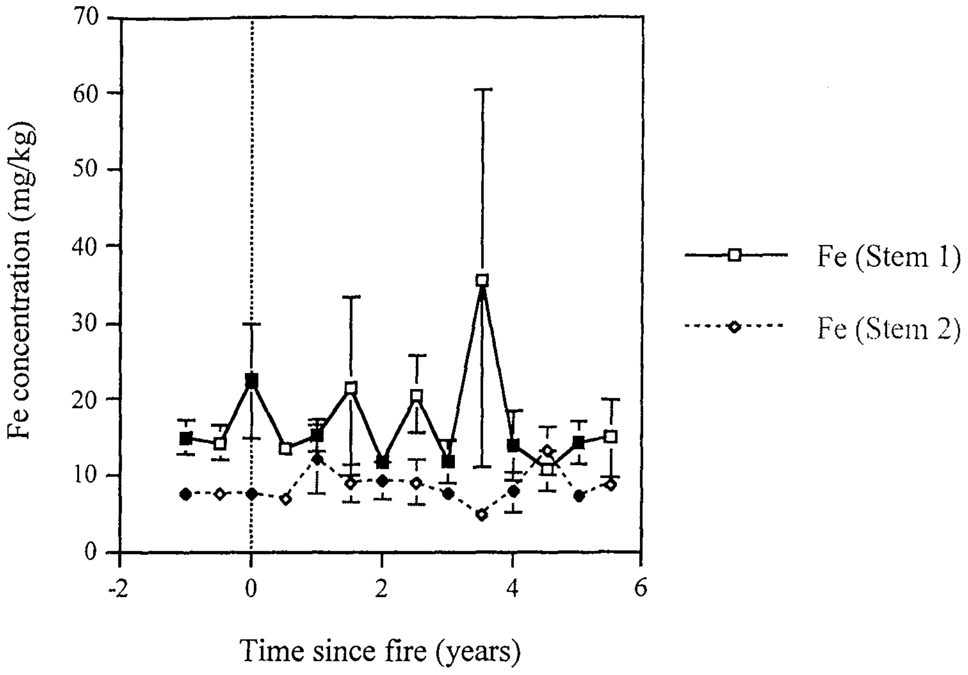

Figure 4-30. Mean Fe concentration in the 1st cm section of leaf bases from Stem 1 and 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

Only insignificant relationships between fire, season and their interaction in Fe concentration of the 1st cm section of leaf bases from Stem 1 and Stem 2 were detected by a two-way analysis of variance ($\alpha = 0.05$). Due to the many values recorded below the limit of detection, limited data were available for Fe concentration in the leaf bases from Stem 3. Therefore no analyses were performed on this stem.

4.3.8.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) confirmed that the Fe concentration data from the 5th cm section of leaf bases from Stem 1 and Stem 2 are random (Table 4-26). However, the data from the leaf bases of Stem 3 are not random.

Table 4-26. Non-parametric runs test ($\alpha = 0.05$) on the Fe concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	29	153	0.0598
Stem 2	28	74	0.6836
Stem 3	26	66	0.0000

No seasonal or fire effect was apparent within the Fe concentrations of Stem 1. The distinct peak in the Stem 1 concentration of Fe 0.5 years previous to fire can be accounted for by random outliers due to the substantial error associated with this point (Figure 4-31). The data for Stem 2 does exhibit some seasonal variation: a few years after the passage of fire, the mean winter/spring concentration is consistently higher than the summer/autumn level. The concentration of Fe within the 5th cm section of leaf bases from Stem 3 was greater than that in the 1st cm section, although no pattern of variation was apparent within the 5th cm sections.

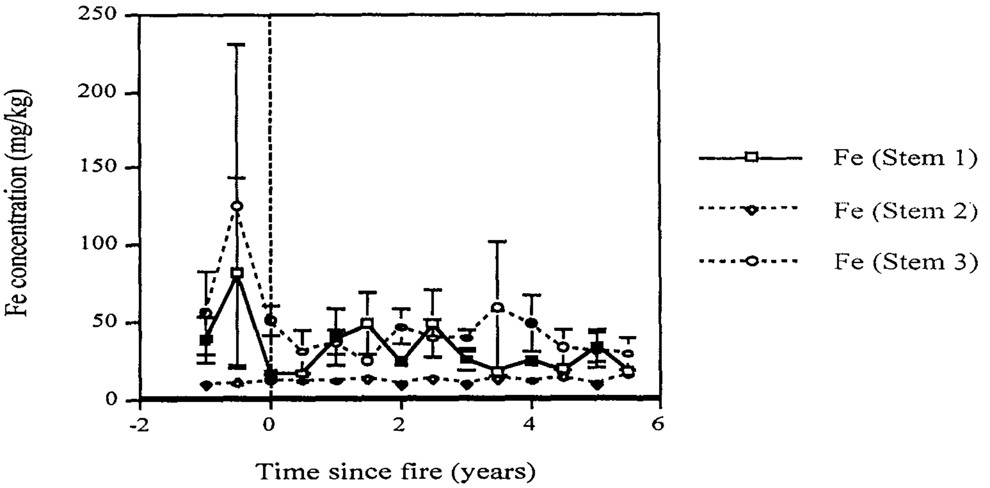

Figure 4-31. Mean Fe concentration in the 5th cm section of leaf bases from Stems 1, 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A winter/spring maximum in the level of Fe is displayed by all 3 stems studied. The difference between the season means is greatest for Stem 1, and smallest for Stem 2. The winter/spring means for both Stem 1 and Stem 3 have substantial levels of variance in comparison to Stem 2.

A two-way analysis of variance ($\alpha = 0.05$) determined that there was no significant difference between the mean Fe concentrations of the 5th cm section of leaf bases from Stem 1. It was therefore concluded that there was no significant fire, season or interaction effect within Stem 1. As expected, a two-way analysis of variance ($\alpha = 0.05$) indicated that the seasonal trend in Fe is significant within the leaf bases of Stem 2 (Table 4-27). No significant fire or interaction effects were detected.

Table 4-27. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Fe within the 5th cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0295
Time since fire	5	0.9556
Interaction	5	0.8197
Residual	42	

A paired *t*-test ($\alpha = 0.05$) performed on the 5th cm section of leaf bases from Stem 3, showed that there was no significant season effect in the concentration of Fe (P = 0.706).

4.3.9 Manganese

4.3.9.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) determined that the sequential Mn concentrations in the 1st cm section of leaf bases from all 3 stems were not random (Table 4-28).

Table 4-28. Non-parametric runs test ($\alpha = 0.05$) on the Mn concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	75	107	0.0004
Stem 2	48	54	0.0031
Stem 3	47	51	0.0155

The concentration of Mn within the 1st cm section of leaf bases from Stem 1 varied substantially through time (Figure 4-32). Both Stem 2 and Stem 3 exhibited a general trending upwards since 1960. Stem 2 had the most concentrated levels of Mn; Stem 3 generally had the most dilute.

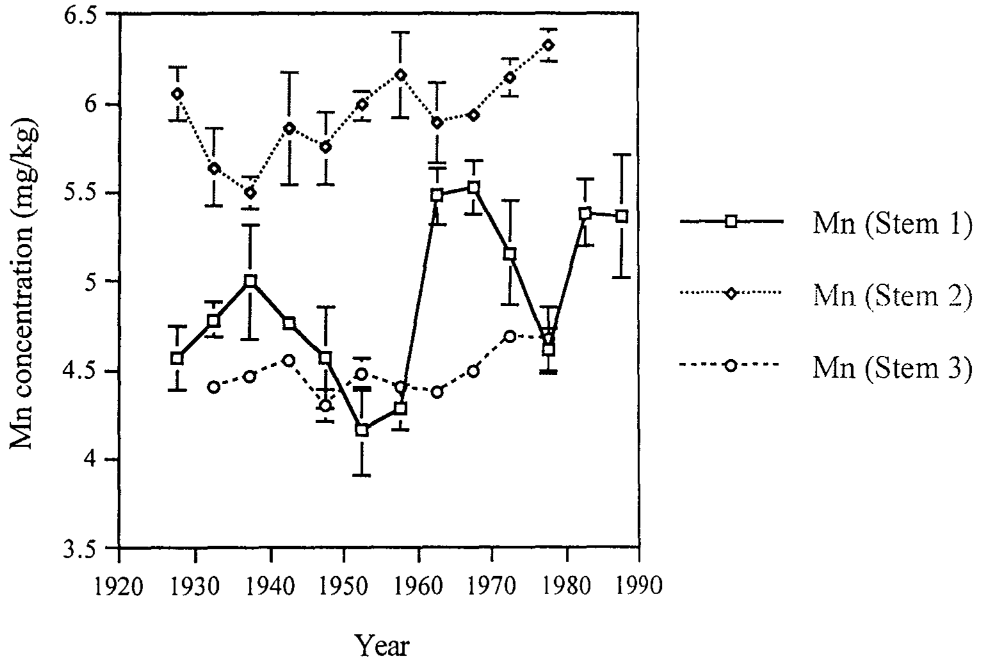

Figure 4-32. Five yearly mean Mn concentration (mg/kg) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

At the time of fire, the concentration of Mn within the 1st cm section of leaf bases peaked in Stem 1 (Figure 4-33). After this initial peak, the concentration of Mn decreased abruptly, returning to pre-fire levels within 1 year.

An increase in the concentration of Mn at the time of fire was also exhibited by Stem 2 (Figure 4-34). The peak in Mn concentration was sustained for longer within the leaf bases belonging to Stem 2. Pre-fire cycling was reinstated 1.5 years after the fire. Limited variation in Mn concentration was seen along the length of Stem 3.

A two-way analysis of variance ($\alpha = 0.05$) was performed to quantify the significance of the fire and seasonal effects. The fire effect on the Mn concentration of the 1st cm section of leaf bases from Stem 1 was highly significant (Table 4-29). There was not a significant season effect, although there was a significant level of interaction between fire and season. In the first year after the passage of fire, the summer/autumn concentration of Mn was significantly greater than the winter/spring level. Conversely, in the second year the winter/spring mean was greater, and in the third the summer/autumn mean was again greater. In the fourth year the winter/spring concentration was higher. This trend was retained into the fifth and sixth years, the final years analysed within the two-way.

Table 4-29. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mn within the 1st cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.5770
Time since fire	5	0.0001
Interaction	5	0.0332
Residual	144	

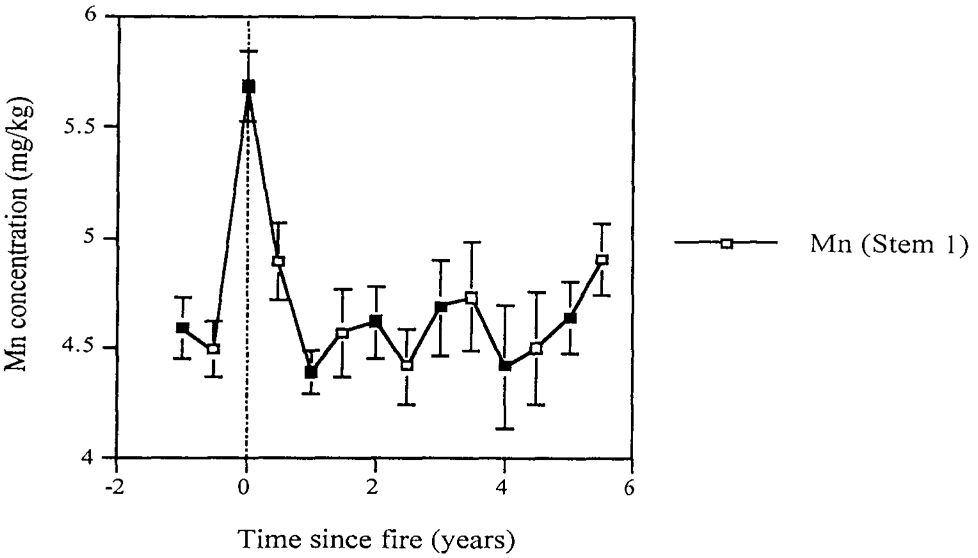

Figure 4-33. Mean Mn concentration in the 1st cm section of leaf bases from Stem 1 and 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

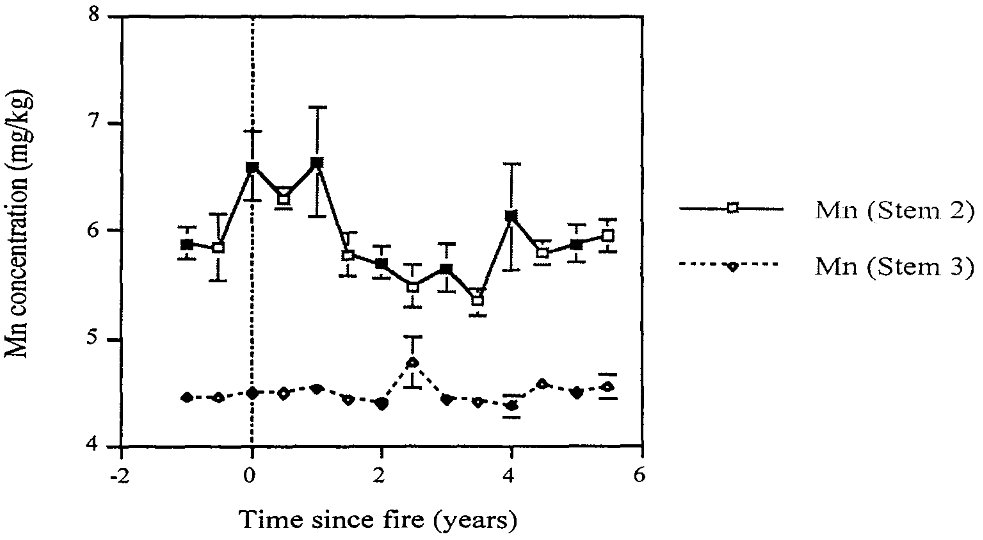

Figure 4-34. Mean Mn concentration in the 1st cm section of leaf bases from Stem 2 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) showed that fire significantly affected the concentration of Mn within the 1st cm section of leaf bases from Stem 2 (Table 4-30). The effect of season was shown to be statistically insignificant ($P = 0.0511$), even though Figure 4-34 displays a regular summer/autumn peak. The interaction between the fire and season effects was shown to be insignificant. A paired *t*-test ($\alpha = 0.05$) confirmed the lack of a significant seasonal effect on Mn concentration within the 1st cm section of leaf bases from Stem 3 ($P = 0.188$).

Table 4-30. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mn within the 1st cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0511
Time since fire	5	0.0062
Interaction	5	0.7074
Residual	42	

4.3.9.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) determined that the sequential Mn concentrations in the 5th cm section of all three stems do not represent random data (Table 4-31).

Table 4-31. Non-parametric runs test ($\alpha = 0.05$) on the Mn concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	73	109	0.0000
Stem 2	35	67	0.0002
Stem 3	34	58	0.0000

Stem 1 and Stem 2 both show seasonal variation in the concentration of Mn within the 5th cm section of their leaf bases (Figure 4-35). The greatest difference between the seasons is seen in Stem 2, where the winter/spring mean is 2.10 mg/kg higher than the summer/autumn level. No fire effect is apparent within either Stem 1 or Stem 2.

The seasonal pattern in the Mn concentrations is very distinctive within the 5th cm section of samples from Stem 3 (Figure 4-37). The mean winter/spring concentration was consistently greater than the summer/autumn level.

The seasonal differences in Mn concentration were consistent but not significantly so within the 5th cm section of leaf bases from Stem 1. However, the season effect was significant within Stem 2 (Table 4-32). A two-way analysis of variance ($\alpha = 0.05$) indicated that there was no significant fire effect or interaction between fire and season within either Stem 1 or Stem 2.

Table 4-32. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Mn within the 5th cm section of leaf bases from Stem 2.

Source	df	*P*
Season	1	0.0041
Time since fire	5	0.9811
Interaction	5	0.6147
Residual	42	

A paired *t*-test ($\alpha = 0.05$) showed that the seasonal Mn concentrations within the 5th cm section of leaf bases from Stem 3 were significantly different. A *P*-value of 0.000 was calculated; the winter/spring mean is significantly greater than the summer/autumn mean, with values of 5.68 mg/kg and 4.32 mg/kg respectively.

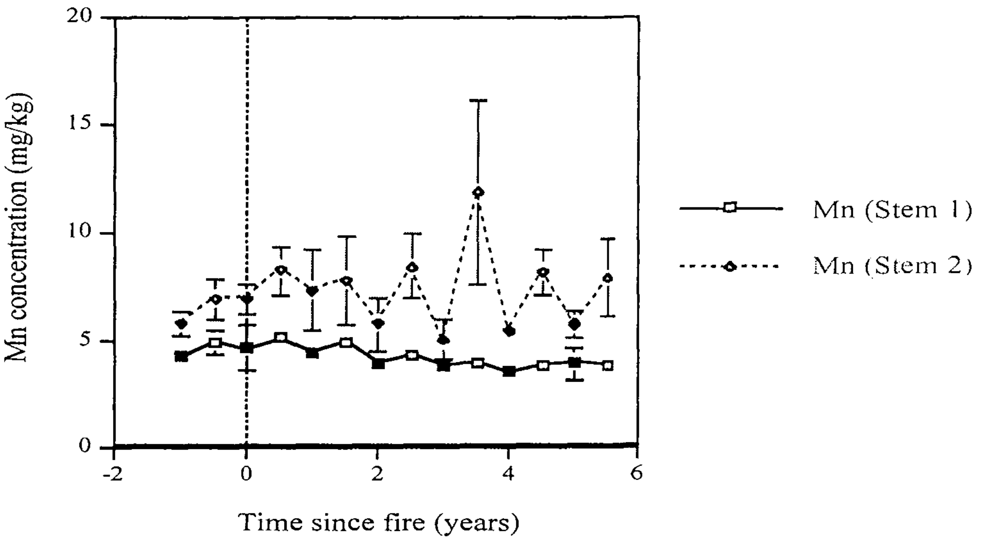

Figure 4-35. Mean Mn concentration in the 5th cm section of leaf bases from Stem 1 and 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

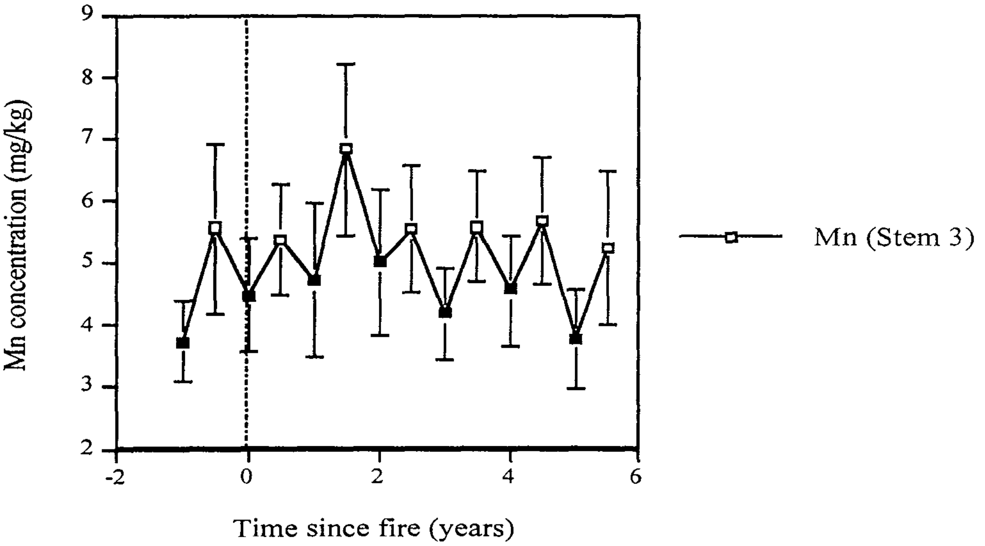

Figure 4-36. Mean Mn concentration in the 5th cm section of leaf bases from Stem 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

4.3.10 Sodium

The leaf base concentrations of Na did not reliably fluctuate above trace levels in both sections for all three stems. It was uncommon to see a concentration above < 0.01 % db (or < 100 mg/kg), which was the limit of detection.

4.3.11 Zinc

4.3.11.1 1st cm section

A non-parametric runs test ($\alpha = 0.05$) was performed on the consecutive Zn concentrations from all 3 stems. It was concluded that the run of data for all three stems was not random; therefore the results reflect the effect of external variables (Table 4-33).

Table 4-33. Non-parametric runs test ($\alpha = 0.05$) on the Zn concentration of the 1st cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	72	110	0.0000
Stem 2	39	63	0.0001
Stem 3	42	56	0.0000

A high level of variation in the concentration of Zn existed within the 1st cm section of leaf bases from Stem 1 (Figure 4-37). A distinct incline in the Zn concentration was present after 1970 in this stem. The levels of Zn within Stem 2 and Stem 3 showed variation over time on a smaller scale than that displayed by Stem 1. The overall Zn content of the 1st cm section of leaf bases from Stem 1 was higher than that in Stem 2 and Stem 3; the latter two stems had concentrations in the same magnitude.

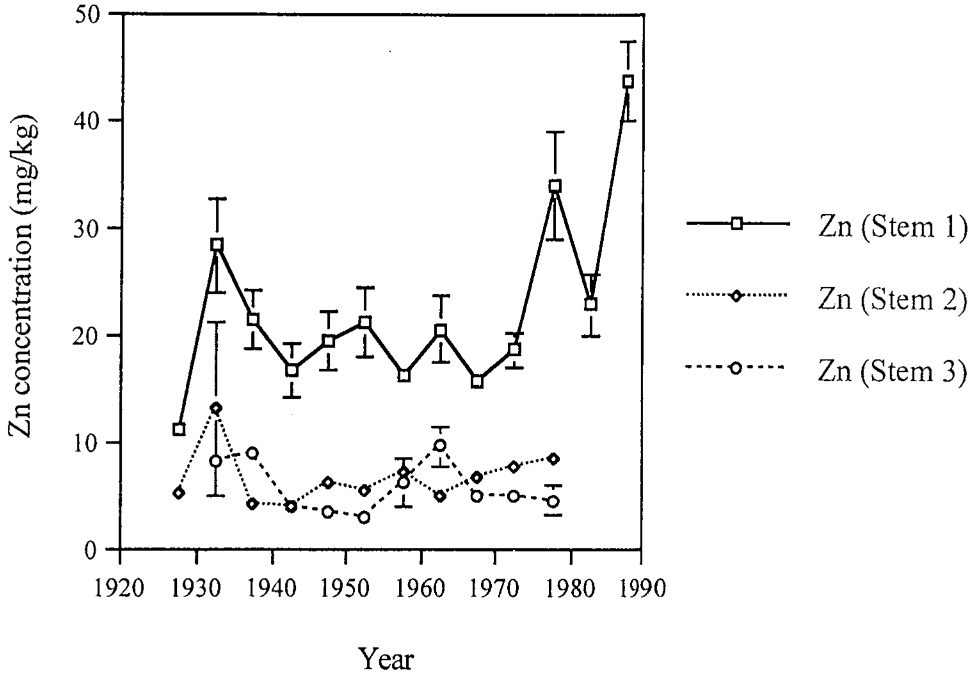

Figure 4-37. Five yearly mean Zn concentration (mg/kg) in the 1st cm section of leaf bases from all 3 stems. (Standard error bars have been included.)

A substantial drop in the concentration of Zn was recorded at the time of fire within the 1st cm section of leaf bases from Stem 1 (Figure 4-38). This initial reduction was followed by a rapid increase; the concentration bypassed pre-fire levels culminating in a peak one year after the fire. A stabilisation of the Zn level was then seen for 2.5 years, which preceded a second peak, 4 years after fire, that reached even higher concentrations than the first. No trends in the concentration of Zn within the 1st cm section of leaf bases from Stem 3 were apparent.

The Zn content of the 1st cm section of leaf bases from Stem 2 dropped slightly at the time of fire. They then recovered to form a peak 1 year after the fire (Figure 4-39). Succeeding this initial reaction to fire, another concentration drop followed by a peak was revealed. The second peak occurred 4.5 years after the passage of fire.

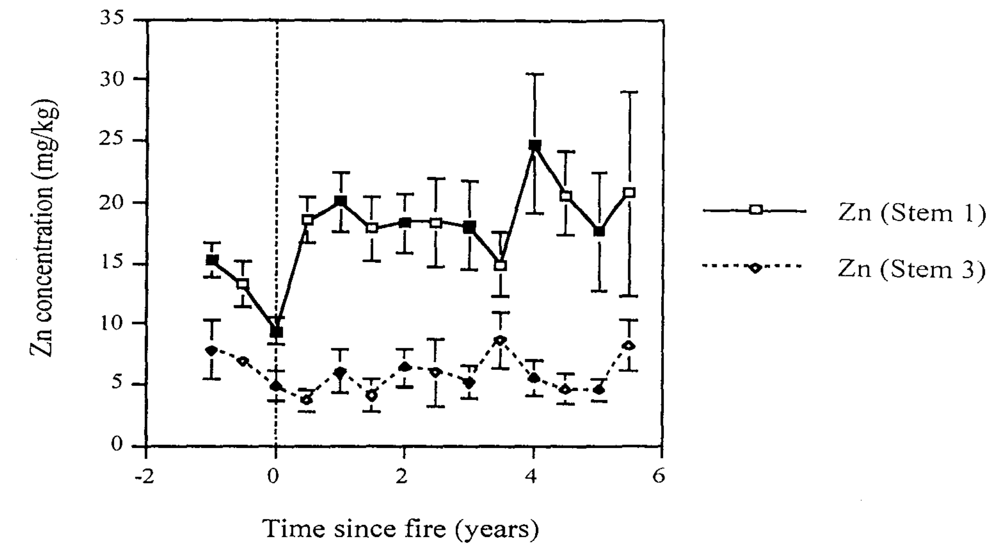

Figure 4-38. Mean Zn concentration in the 1st cm section of leaf bases from Stem 1 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included closed symbols are summer/autumn values, open symbols are winter/spring values.)

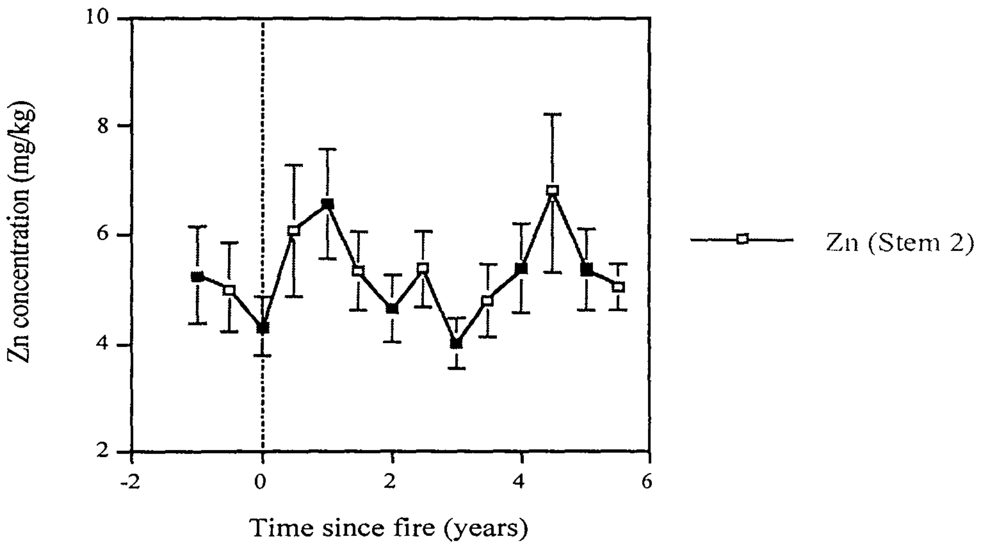

Figure 4-39. Mean Zn concentration in the 1st cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) was performed to determine the scale of influence from fire, season and the interaction between the two, on Zn levels within the 1st cm section of Stem 1. It was concluded that there was no significant effect from season, a significant effect from fire and a significant level of interaction between the two (Table 4-34). The mean summer/autumn concentrations of Zn were greater than the mean winter/spring concentrations within the analysis for Stem 1. The only exceptions occurred at the time of fire when the winter/spring level was significantly greater than the summer/autumn level, and in the sixth year after the passage of fire (the final year tested), when the seasonal values were almost equivalent. All three combinations of factors were found to have no significant ($\alpha = 0.05$) effect on the level of Zn within the 1st cm section of leaf bases from Stem 2. The Zn levels within the 1st cm section of leaf bases from Stem 3 showed no significant seasonal variation ($P = 0.700$, *t*-test).

Table 4-34. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Zn within the 1st cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.8025
Time since fire	5	0.0224
Interaction	5	0.0045
Residual	144	

4.3.11.2 5th cm section

A non-parametric runs test ($\alpha = 0.05$) showed that the sequential Zn concentrations in the 5th cm section of leaf bases from Stem 2 were random (Table 4-35). The same test indicated that the consecutive concentrations within the 5th cm section of leaf bases from Stems 1 and 3 were not random.

Table 4-35. Non-parametric runs test ($\alpha = 0.05$) on the Zn concentration of the 5th cm sections of all 3 stems.

	# observations above K	# observations below K	*P*
Stem 1	67	115	0.0000
Stem 2	40	62	0.1667
Stem 3	33	59	0.0000

The Zn concentration within the 5th cm section of leaf bases from Stem 1 mimicked the pattern seen previously for the 1st cm section from the same stem. There was a drop in concentration at the time of fire, the rapid increase immediately after, stabilisation for three years, and later, a larger peak at 4.5 years after the fire (Figure 4-40). No pattern in the Zn content of the 5th cm section of leaf bases from Stem 3 was apparent.

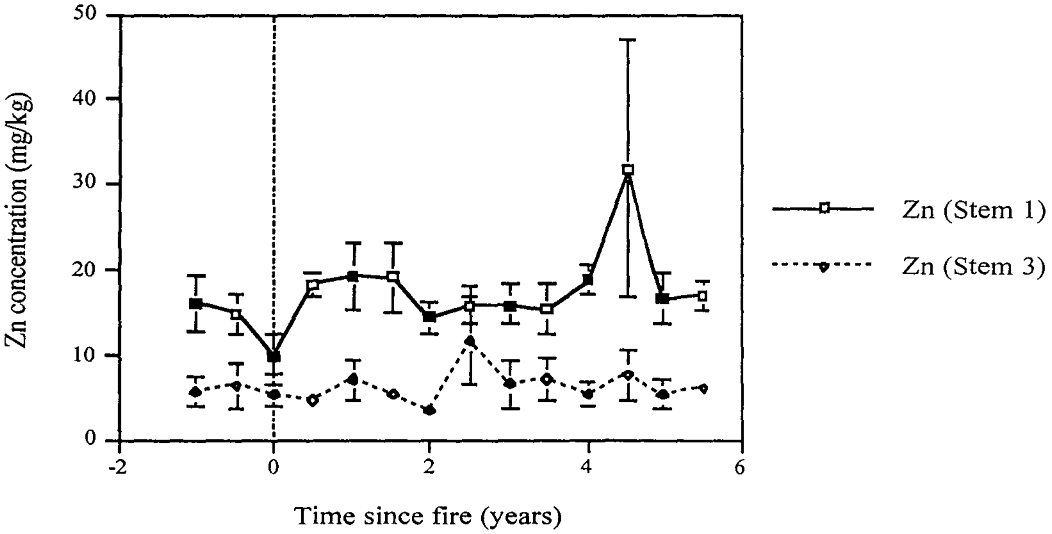

Figure 4-40. Mean Zn concentration in the 5th cm section of leaf bases from Stem 1 and 3 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. Stem 3 was assigned an arbitrary starting point as no fires occurred along its length. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

The Zn concentration within the 5th cm section of leaf bases from Stem 2 displayed an increase after the passage of fire (Figure 4-41). No seasonal variation in the Zn concentrations was apparent. The concentration of Zn was lower within samples from Stem 2 compared to Stem 1; the scale of variation was also reduced. Stem 2 and Stem 3 concentrations were in an equivalent range.

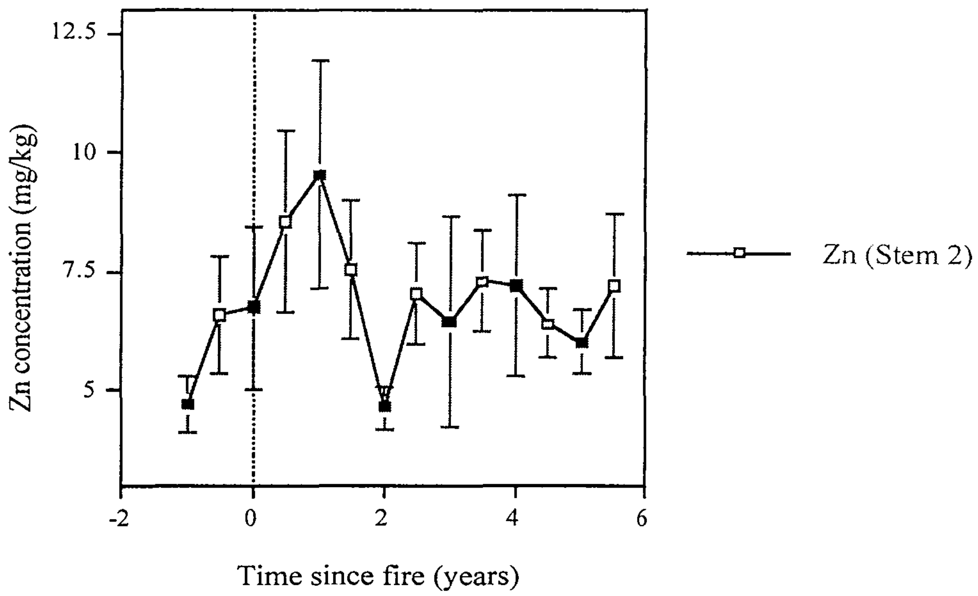

Figure 4-41. Mean Zn concentration in the 5th cm section of leaf bases from Stem 2 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

A two-way analysis of variance ($\alpha = 0.05$) showed that the effect of season on the concentration of Zn was insignificant within the 5th cm section of Stem 1 (Table 4-36). However, it also found that the effect of fire was significant, as was the interaction effect between the two. In the first year after the passage of fire the mean winter/spring concentration of Zn was significantly greater than the summer/autumn level. This is where the interaction effect occurs as the passage of fire is introducing increased variation between the seasons. The difference between the summer/autumn and winter/spring Zn concentration means was negligible for the remaining years included in the analysis of variance. No significant effect of fire, season or interaction was seen within the Zn concentration in the 5th cm section of leaf bases from Stem 2.

Table 4-36. Two-way analysis of variance ($\alpha = 0.05$) results for the concentration of Zn within the 5th cm section of leaf bases from Stem 1.

Source	df	*P*
Season	1	0.1515
Time since fire	5	0.0356
Interaction	5	0.0032
Residual	144	

A paired *t*-test ($\alpha = 0.05$) conducted on the mean winter/spring, and mean summer/autumn, 5th cm Zn concentrations of leaf bases from Stem 3, gave a *P*-value of 0.207. It was therefore concluded that there was no significant seasonal variation within the 5th cm section of leaf bases from Stem 3 either.

4.3.12 Nitrogen

From the limited data collected, it appears that N concentration increases immediately after the passage of fire. Figure 4-42 shows an initial increase in winter 1931 which is connected with a fire in the summer of 1930/31. A fire also occurred in 1935/36, and a post-fire increase in the concentration of N is again observed.

An increase in the N content immediately following fire is again recorded in Figure 4-43. A fire was recorded in 1984/85, immediately after which a peak is present. The magnitude of the N concentrations recorded for the 1980's (range 0.35 to 0.47) is much greater than those for the 1930's (0.18 to 0.26). It appears that the N concentration increases markedly up the stem with the maximum values in the youngest leaf bases.

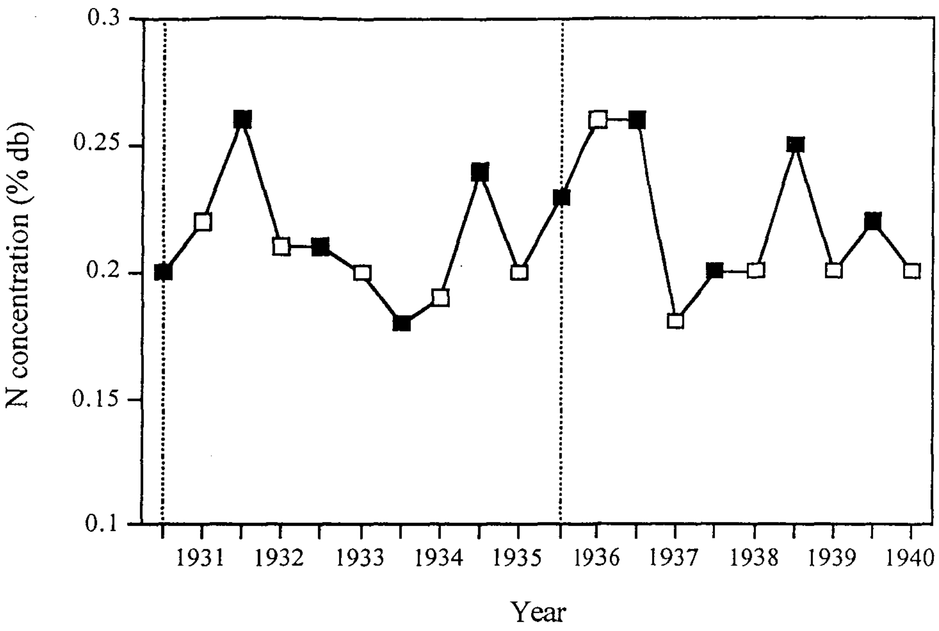

Figure 4-42. Changes in N concentration in the 1st cm section of leaf bases from Stem 1 for the period summer/autumn 1930/31 to winter/spring 1940. (Broken line indicates the time of the passage of fire; closed symbols are summer/autumn values, open symbols are winter/spring values.)

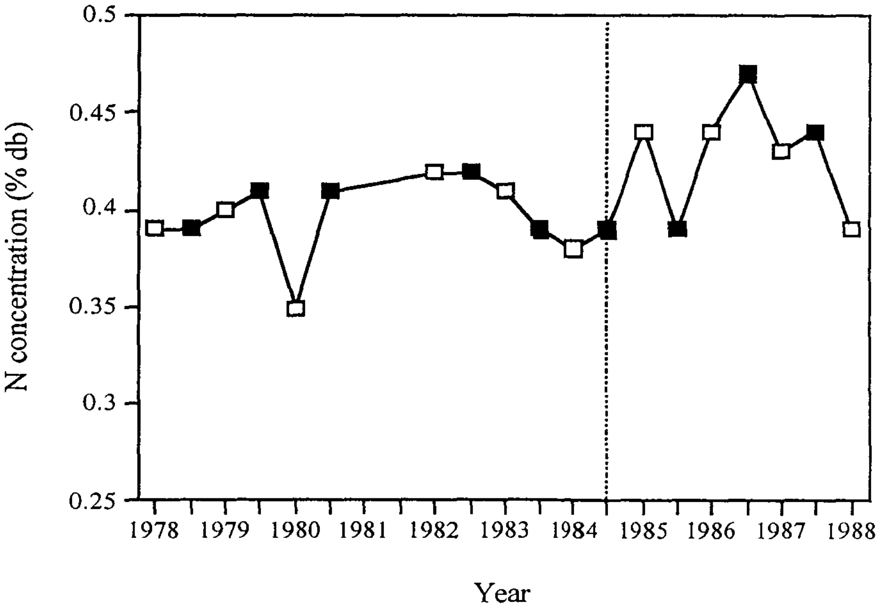

Figure 4-43. Changes in N concentration in the 1st cm section of leaf bases from Stem 1 for the period winter/spring 1978 to winter/spring 1988. (Broken line indicates the time of the passage of fire; closed symbols are summer/autumn values, open symbols are winter/spring values.)

Figure 4-44 clearly demonstrates the increase in N after fire. Only the means for the 1930-1940 data (n = 2) have been presented due to the scale difference with the 1978-1988 data. A runs test was performed on the results to determine whether or not the changes in N were random. It was concluded at a significance level of 0.05 that the data were random. However, due to the small data set the results are inconclusive. The substantial differences in the magnitude of the concentrations for the two decades prohibited any analysis between them. Also the data within each decade were insufficient for them to be analysed independently. It certainly appears that a significant trend in N concentration after the passage of fire exists, as well as greater values in summer/autumn than winter/spring (Figure 4-44), even though they could not be tested here.

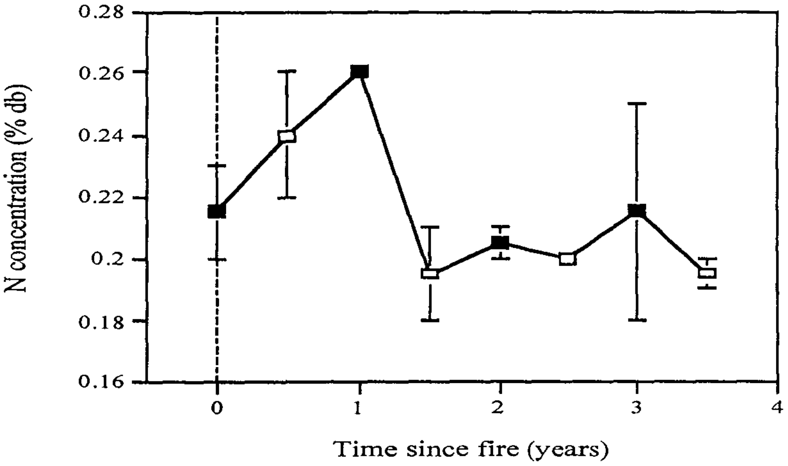

Figure 4-44. Mean N concentrations in the 1st cm section of leaf bases from Stem 1 as time since fire increases. 0 years (broken line) represents the time of the passage of fire. (Standard error bars have been included; closed symbols are summer/autumn values, open symbols are winter/spring values.)

4.3.13 Soil analyses

The results from a one-way analysis of variance (α = 0.05) comparing the soil nutrient levels between sites have been summarised in Table 4-37. The levels of nitrate,

Table 4-37. Soil nutrient analysis results for each site (mean ± sd); Gyngoorda (Site 1), Poison Gully (Site 2) and Amphion (Site 3). All nutrient units are mg/kg, except organic C (%) and the four exchangeable nutrients (meq/100 g). Values with the same superscript are not significantly different (∝ = 0.05) according to Duncan's new multiple range test. Exc. = exchangeable.

Nutrient	Site 1	Site 2	Site 3	*P*
Nitrate	3.00 ± 0.00^{a}	3.67 ± 1.53^{a}	1.33 ± 0.58^{a}	0.0553
Ammonium	7.33 ± 1.16^{a}	5.67 ± 3.06^{a}	6.33 ± 1.53^{a}	0.6367
P	1.67 ± 0.58^{a}	1.33 ± 0.58^{a}	1.67 ± 0.58^{a}	0.7290
K	217.67 ± 43.66^{a}	167.00 ± 36.66^{a}	200.33 ± 49.90^{a}	0.4096
S	8.17 ± 1.42^{a}	5.73 ± 1.76^{a}	9.23 ± 0.91^{a}	0.0671
Organic C	3.09 ± 1.00^{a}	2.42 ± 0.74^{a}	3.63 ± 0.23^{a}	0.2063
Iron	918.67 ± 159.63^{a}	2139.33 ± 149.69^{a}	885.00 ± 294.57^{a}	0.6649
pH (water)	6.40 ± 0.10^{a}	5.93 ± 0.06^{a}	6.37 ± 0.38^{a}	0.0824
B	0.77 ± 0.46^{a}	0.73 ± 0.21^{a}	3.57 ± 4.28^{a}	0.3444
EDTA Cu	0.22 ± 0.11^{b}	0.53 ± 0.11^{a}	0.27 ± 0.08^{b}	0.0209
EDTA Zn	1.87 ± 0.55^{b}	1.30 ± 0.38^{b}	3.69 ± 0.56^{a}	0.0027
EDTA Mn	7.23 ± 2.38^{c}	39.43 ± 11.53^{b}	64.67 ± 9.20^{a}	0.0006
EDTA Fe	42.53 ± 8.69^{b}	86.50 ± 35.78^{ab}	106.07 ± 10.44^{a}	0.0314
Exc. Ca	4.58 ± 2.14^{ab}	3.01 ± 0.94^{b}	8.03 ± 2.26^{a}	0.0421
Exc. Mg	1.36 ± 0.38^{a}	1.47 ± 0.42^{a}	2.34 ± 0.43^{a}	0.0512
Exc. Na	0.27 ± 0.06^{a}	0.26 ± 0.02^{a}	0.32 ± 0.02^{a}	0.1626
Exc. K	0.58 ± 0.10^{a}	0.38 ± 0.09^{a}	0.45 ± 0.07^{a}	0.0749

ammonium, P, K, S, organic C, Iron, pH (water), B, exchangeable Mg, exchangeable K and exchangeable Na did not significantly differ between the 3 sites sampled. However, the levels of EDTA Cu, EDTA Zn, EDTA Mn, EDTA Fe and exchangeable Ca were found to differ significantly. The concentration of Cu was found to be significantly higher in the soil from the Poison Gully site, the remaining two sites were not significantly different from each other. The concentration of Zn was highest in the soils from the Amphion site, once again the remaining two sites, Gyngoorda and Poison Gully were not significantly different from each other. The concentrations of Mn within the soils from the three sites were all significantly different from each other. The highest Mn level was recorded within Amphion site soil (64.67 mg/kg), and the lowest within the soil from Gyngoorda (7.23 mg/kg). The concentration of EDTA Fe within the soil from Amphion (106.07 mg/kg) was significantly higher than the concentration within the Gyngoorda soil (42.53 mg/kg). The Poison Gully site (86.50 mg/kg), possessed an intermediate concentration between these two sites, it was not significantly different from either. The extractable Ca concentration was highest within the soils from Amphion and lowest within the Poison Gully samples. The mean Ca content of Amphion soils was not significantly different from Gyngoorda levels; however, it was different from Poison Gully. The Ca concentrations within Gyngoorda and Poison Gully were not significantly different from each other.

4.4 DISCUSSION

4.4.1 Phosphorus

Low concentrations of P within the leaf base samples were expected, a reflection of the general deficiency of P within the substrate (Beard 1990). Even though low concentrations were expected, levels below the technique's sensitivity were not. The leaf base concentrations of P recorded in this study were at least two times lower than previous results for related plants. Foulds (1993) recorded P concentrations in the range 0.2 to 1.1 mg g^{-1} (0.02 to 0.11% db) within plant foliage from various south-western

Australian habitats. Specht et al. (1958) recorded a mean P content of 224 ppm (0.02% db) in the leaves of 10 specimens of *X. australis* at Dark Island, South Australia.

Even if leaf bases formed during ambient conditions contained trace levels of P, after the passage of fire an increase in P availability within the soil and therefore P assimilation should have resulted in a reading greater than 0.01% db. A post-fire increase in P availability within the soil has been widely reported (Loneragan and Loneragan 1964, Adams et al. 1994, Carreira and Niell 1995, Tomkins et al. 1991). An increased foliar concentration of P has also previously been detected. Grove et al. (1980) recorded a significant increase in the P concentration of *M. riedlei* leaves following fire, as did Humphreys and Lambert (1965) for the leaves of *Pinus radiata*.

A number of factors may be reducing the levels of P uptake by the grasstree roots, resulting in decreased foliar levels. Volatilisation of P at the time of fire decreases the scale of concentration increase within the soil, reducing P availability to roots. Raison et al. (1985b) reported P transfer to the atmosphere during a low intensity prescribed fire in subalpine eucalypt forest as 1.96 - 3.04 kilograms per hectare. This figure is significant when the total P pool and low rates of input are considered.

The post-fire increase in P may be very short-lived allowing plant roots insufficient time to exploit the elevated levels. P mobilised from the litter may be quickly immobilised again due to the strongly-fixing lateritic soils (O'Connell et al. 1978). Vlamis et al. (1955) found no significant change in available P levels following fire on loam. They attributed this to the P binding strength of the soil. Another alternative is that P may be quickly removed from the soil due to the influence of other elements. At a pH of 6 or more, Ca removes P; at a pH below 6, Al and/or Fe will affect P, or all of these in the slightly acidic range of 6 to 7 (Attiwill and Leeper 1987).

In the immediate post-fire environment, movement of P in particulate form may also be decreasing the amount of P available for uptake. Williams and Raupach (1983) found that surface accumulation of phosphate and organic P increases the risk of nutrient loss through erosion, and surface drying may, at times, deny the plant roots full access to the readily available phosphate. Hall (1994) reported that at least 30 times more P was lost in runoff from burnt plots than from unburnt plots. Leaching is unlikely to be significantly affecting uptake, as P is normally highly resistant due to the binding strength of the lateritic soils (Richards and Charley 1983).

Following uptake by the roots a number of factors may decrease the concentration of nutrients within leaf base tissues. These include retranslocation of P prior to leaf senescence (see O'Connell et al. 1978), and high levels of leaching upon deposition within the leaf base. The high mobility of P within plant tissues (Brown and Shelp 1997) is central to both these possibilities. O'Connell et al. (1978) reported 80% withdrawal of the P contained in leaves of jarrah and marri prior to senescence. Internal recycling of P is very important to jarrah forest vegetation due to the low levels of this element in the external environment. Retranslocation would decrease the detectable levels of P within the light brown and dark brown bands, but not within the black bands. The leaf bases forming the black bands do not have the opportunity to senesce before they are killed by fire, therefore retranslocation of nutrients is not implemented. Sutcliffe and Baker (1974) reported that considerable amounts of some elements are leached from leaves as a result of rain or dew. The reduction of P by leaching from leaves is highly probable due to its high mobility within plant tissues. Any of these factors may be causing the low foliar levels of P recorded within this study.

4.4.2 Calcium

The concentrations of Ca within the leaf bases from Stem 1 were slightly lower in the older leaf bases sampled. This may be due to some leaching of Ca over time. Adams and Attiwill (1986) recorded limited throughfall of Ca in eucalypt forests of south-eastern Australia, although the levels were variable and insignificant at most of the plots studied. Overall, it is thought that the concentration of Ca within the leaf bases is representative of historical levels. Even if Ca is leached slightly the level of leaching will be relatively constant for all leaf bases. Therefore, general trends in the concentration of Ca along the stem are retained.

The mean concentration of Ca within the 1st cm section of leaf bases was greatest in Stem 1, and lowest in Stem 3. However, within the 5th cm section, Stem 3 possessed the highest concentrations, and Stem 1 and Stem 2 had concentrations in an equivalent range. These differences can be explained by differences in the level of soil Ca between sites for the 5th cm section only. Extractable Ca levels were greatest in the soils from the Amphion site and lowest in soil from Poison Gully. This is consistent with the trends seen within the 5th cm section but not the first.

The passage of fire had a significant effect on the concentration of Ca within the grasstree leaf bases. The Ca concentrations within the leaf bases were minimal at the time of the passage of fire. This is probably because phloem-immobile Ca continues to accumulate in leaves throughout their life (Attiwill and Leeper 1987). The normal life span of the burnt leaves was cut short, and therefore maximal levels of Ca were not reached. Within jarrah and marri, Ca increases in concentration by about 30% prior to litter fall (O'Connell et al. 1978). Therefore, the accumulation of Ca within the ignited leaf bases was ended prematurely, resulting in reduced levels of Ca.

After the immediate drop in Ca a rapid period of Ca assimilation was exhibited. This is attributed to high concentrations of available Ca in the soil after the addition of ash. Raison et al. (1985b) found that, in comparison with unburnt *E. pauciflora* litter, Ca concentrations were increased 10- to 50-fold in fine (< 1 mm) ash. Grove et al. (1996) and Juo and Manu (1996) both recorded the relative input of each nutrient and concluded that the levels of addition were greatest for Ca. Fire increases the availability of Ca by remobilising it from bound forms within the soil and by releasing it from concentrated stores within organic material. The increased Ca availability within the soil would have instigated rapid uptake by plant roots and therefore the elevated foliar Ca levels recorded in this study.

Ca concentrations would have been further increased if Ca was selectively absorbed by plant roots. Some ions appear unable to compete with Ca^{2+} for sorption sites at near-neutral pH (Harter 1992). Attiwill and Leeper (1987) recorded the order of competing power when present in equivalent amounts as Ca > Mg > K > Na. Therefore, the peak in foliar levels may not only be due to increased soil availability but also competitive uptake of Ca. An exception occurs when the concentration of Mg is greater than Ca (a rare situation), insufficient Ca may be available for absorption (McColl 1969).

Ca elevation was sustained for a longer period when compared with the other nutrients studied. The duration of the increases in cation levels is related to their soil mobility and the occurrence of rainfall subsequent to burning (Tomkins et al. 1991). In most soils, cation exchange reactions will prevent the soluble Ca in ash from moving beyond the root zone (Richards and Charley 1983).Therefore, low mobility of Ca within the soil may have extended the period of the fire effect. Tomkins et al. (1991) recorded elevated exchangeable Ca levels after two years and approximately 2000 mm of rain. An increase in pH acts to increase the retention of bases added in ash by increasing the net negative charge (Khanna et al. 1994). Erosional losses may decrease the degree and duration of increased Ca levels. Hall (1994) recorded 100 times more Ca in runoff from burnt plots.

There was a clear seasonal effect on the concentration of Ca within grasstree leaf bases. This effect was very distinct in the 5th cm section of leaf bases from Stem 1 and Stem 3. It is thought to be due to seasonality within the environment, where the bulk of growth is restricted to the winter/spring period, and a seasonal pattern of cation availability. Tomkins et al. (1991) reported that during a dry period (usually summer) many organisms in the surface soil expire, and wetting during the first substantial rainfall then leads to a release (flush) of nutrients. A drop in Ca at the time of fire induced the significant interaction effect, as the drop was restricted to the summer/autumn period. Therefore, the fire effect reduced the overall mean summer/autumn concentration and interfered with the seasonal comparison.

4.4.3 Potassium

All three stems displayed a general decrease in the concentration of K through time, peaking in the youngest samples. K is highly mobile within plant tissues and is therefore highly susceptible to leaching when senescing foliage is subjected to precipitation (Nelson et al. 1995). It is thought that the K content of the leaf bases may be leached to a base level. The incline in concentration seen in recent years is probably because the younger leaf bases have yet to be exposed to enough weathering to be thoroughly leached of K and have therefore not yet reached this minimum concentration. A number of studies have reported high levels of K leaching from plant tissues (Adams and Attiwill 1986, O'Connell 1989). O'Connell et al. (1979) found that more K is cycled in canopy throughfall than in litter fall. It is inevitable that leaching of K from the leaf bases will occur.

The availability of K in forest soils characteristically increases after the passage of fire (Grove et al. 1986, Khanna et al. 1994, Tomkins et al. 1991). It would be expected that this elevated availability would be reflected by increased foliar levels of K. However, an insignificant fire effect was recorded for both cm sections of leaf bases from Stem 1 and Stem 2, even though immediate post-fire increases were obvious within the youngest leaf bases from Stem 1. It is suggested that the fire effect may have been leached from the older leaf bases. Increased levels of K in throughfall have been reported after fire (O'Connell et al. 1979). This would explain why the fire response is clear within the younger leaf bases yet not detectable within the older ones.

An alternative explanation for the insignificant fire effect would be that the uptake of K is restricted within the post-fire environment. High soil concentrations of Ca often decrease the availability of K (Jakobsen 1996, Sutcliffe and Baker 1974), as Ca out competes K when present in equivalent amounts (Attiwill and Leeper 1987). This would mask the increased levels of K within the soil after fire, preventing increased K assimilation. When the inter-fire interval is short, as seen in the older sections of Stem 1, levels of Ca would be constantly elevated. This would act as a permanent barrier to K uptake. As the frequency of fire has decreased over time this restriction on K uptake, instigated by increased Ca levels, would be weakened as the elevated Ca concentrations are not maintained. Therefore, the increased post-fire availability of K would be reflected within the youngest leaf bases only.

4.4.4 Magnesium

It has previously been established that the availability of Mg increases after the passage of fire due to remineralisation and deposition in ash (Trabaud 1983, Williams and Raupach 1983). Grove et al. (1986) recorded a 55% increase over pre-burn concentrations of extractable Mg within jarrah forest soils. The immediate increase in the concentration of Mg within the soil was not reflected by an increase in the leaf base foliar levels. This is thought to be due to the effect of high concentrations of Ca on the behaviour of Mg in the post fire environment. Ca outcompetes Mg for sorption sites when present in equivalent amounts (Attiwill and Leeper 1987). The competitive power of Ca is further increased as the relative amounts of exchangeable Ca in forest soils are not only equivalent to Mg, but greater (Attiwill and Leeper 1987). Further more, the increases in the concentrations of Ca after fire occur on a larger scale than the comparative increases of Mg. These factors act to restrict the uptake of Mg by the grasstree roots while the levels of Ca remain elevated. The delayed peak in Mg approximately 4 years after the fire may be due to the eventual abatement of the elevated Ca levels. Conditions returned to pre-fire concentrations after this latter peak.

Leaf bases from Stem 2 contained the highest concentrations of Mg, Stem 3 the lowest. This variation between stems may be explained using a similar theory to that presented above. The concentration of Mg is highest within the soil from Site 3, yet the foliar levels from this site are the lowest. However, the Site 3 concentrations of Ca are significantly higher than the levels within Site 2, where the highest foliar levels were recorded. The foliar concentration of Mg may be negatively correlated to the soil levels of Ca, due to the restrictions on Mg uptake described.

A significant winter/spring peak in the concentration of Mg existed within the 5th cm sections of leaf bases from Stem 2 and Stem 3. This pattern can again be ascribed to annual drying and wetting cycles (Tomkins et al. 1991), similar to those seen in Ca. The significant interaction effect recorded between fire and season within Stem 1, is the result of the peak in Mg concentration at the time of fire increasing the overall mean summer/autumn concentration.

4.4.5 Sulfur

The concentrations of S within the leaf bases of all 3 stems decreased through time, peaking in the youngest samples. This is due to the susceptibility of S to leaching, a consequence of its mobility within plant tissues (Sutcliffe and Baker 1974). An alternative explanation is related to the increasing concentration of S in the atmosphere from pollution. Miller et al. (1976) reported significant aerosol entrapment of S within the crowns of mature forest. Increases in the concentration of S within the atmosphere would lead to increased accessions of S by vegetation. This is unlikely within the Perth region though, as pollution problems are not as dire as those reported elsewhere.

The 5th cm section of remnant leaf bases from Stem 1 displayed a significant peak in the concentration of S at the time of fire. This peak could be attributed to the cessation of retranslocation processes that would normally reduce S levels upon leaf senescence (O'Connell et al. 1978). Even though S is prone to sizeable losses to the atmosphere during combustion (Juo and Manu 1996), the overall soil availability of S is increased in the immediate post-fire environment. Grove et al. (1986) reported an increase of 242% over pre-burn concentrations of extractable S. However, this post-fire increase in the concentration of S was not evident in the 1st cm section of the leaf bases. The S concentrations within the 5th cm sections actually did rise initially, recovering by the second year. This small response may be due to the influence of increased post-fire concentrations of Ca. Sulfate is fairly soluble in the absence of Ca^{2+}, but in the presence of calcium its solubility is reduced by its precipitation as $CaSO_4$ (Taiz and Zeiger 1991). This would inhibit uptake of S by the grasstree roots leading to decreased foliar levels until Ca concentrations had subsided. If so, the return of Ca to pre-fire levels is reflected by the secondary peak in the concentration of S.

A significant summer/autumn peak in the concentration of S was recorded within the leaf bases of Stem 3. This may be due to the higher level of rainfall received at the Amphion site indicating a delay in the characteristic spring growth flush. The soils at the Amphion site would be moister for a longer period of time over the winter/spring period. Rapid assimilation of nutrients may occur later in the year at this site when soil moisture levels are optimal. In conjunction with this, the extremely thick litter and humus layer at the Amphion site may delay soil wetting by restricting moisture penetration, and act to delay soil drying into the summer months. It is also possible that retranslocation is more efficient from the winter/spring formed leaves than the summer/autumn leaves. The first two suggestions may also serve as explanations for the unusual correlation of the white coloured bands with the trough of the stem fluctuations, seen previously in the Amphion stem (Chapter 3). The growth flush occurs later due to the increased moisture availability, however the seasonal formation of the coloured bands remains the same.

4.4.6 Boron

The highest concentrations of B were recorded in the youngest leaf bases sampled. This again may be due to leaching losses of B, even though it is generally considered to exhibit restricted mobility within plant tissues. Brown and Shelp (1997) demonstrated that the phloem mobility of boron is species dependent. They concluded that in species producing significant amounts of polyols in source leaves, boron is readily translocated as a consequence of the formation of B-polyol complexes. Further investigations need to be conducted to determine the mobility of B within *X. preissii* before further explanations are suggested.

The concentration of B within soils increases after the passage of fire (Raison et al. 1985b). The rise in B availability was reflected by a peak in concentration within the leaf bases from Stem 1, but not Stem 2. The absence of a peak in Stem 2 could be attributed to restricted uptake of B due to the increased pH induced by fire. Raising the pH causes B to become less available and results in reduced levels of absorption (Sutcliffe and Baker 1974). The effect of pH may have reduced the magnitude of increase displayed within Stem 1. The cause of the low B concentrations four years after the passage of fire is unknown. The concentration of B within soils after the passage of fire may decrease below pre-fire levels before recovering.

The 5th cm section of leaf bases from Stem 1 showed a dramatic drop in the concentration of B at the time of fire. This drop may be attributed to volatilisation of B, due to the exposure of this exterior section of the leaf base to high temperatures during combustion. High non-particulate transfer has previously been reported: Raison et al. (1985b) recorded the mass range of B transferred to the atmosphere during a low-intensity prescribed burn in three Australian alpine eucalypt forests as 35-54% of pre-fire fuel levels. Restricted deposition of B due to the premature death of leaf bases is an alternative explanation. Further conclusions can be made when the mobility of B within *X. preissii* tissues is known.

No general trend in seasonal variation was displayed by the leaf base concentrations of B. A significant summer/autumn peak was recorded in the 1st cm section of leaf bases from Stem 3. However, a significant winter/spring peak was recorded within the 5th cm section of leaf bases from Stem 1. These differences are contradictory, therefore no conclusions can be made. Significant interaction existed within the 5th cm section of samples from Stem 1 due to the presence of the substantial drop at the time of fire causing a reduction in the overall summer/autumn mean.

4.4.7 Copper

Cu composition of the leaf bases displayed no consistent trends through time. Instead high levels of random variation were apparent. No significant fire effect was evident in the 1st cm section of leaf bases from all three stems. A significant fire effect was shown to exist within the 5th cm section of leaf bases from Stem 1. However, this response to the passage of fire was not consistent with the trend seen in the 1st cm section of leaf bases from the same stem. The Cu concentration within the 1st cm increased after fire (not significant) whereas it increased at the time of fire and than decreased below non-fire levels over the next two years within the 5th cm section. A decrease in Cu availability after fire is the most likely trend, as increased pH and increased phosphate levels reduce its availability (Sutcliffe and Baker 1974). The addition of phosphate in ash may instigate Cu precipitation as insoluble Cu phosphates. The slow recovery of Cu concentrations displayed by Stem 1 (5th cm) would coincide with the restoration of pH to pre-fire levels.

Elevated Ca levels are not thought to be responsible for reduced uptake of Cu in this case, even though Herbert (1991) found that foliar Cu within *Eucalyptus grandis* W. Hill ex Maiden was negatively correlated to exchangeable soil Ca. Harter (1992) reported unhindered adsorption of Cu^{2+} in the presence of Ca^{2+}, although he did record decreased adsorption of Cu^{2+} in the presence of Zn^{2+} at pH above 5. The contradictions make it impossible to determine a customary response of Cu to the passage of fire. Even though a general response is not clear, it is important to note that fire is having a significant effect on the concentration of Cu within the grasstree leaf bases. Further research of this type will define the recurrent reaction to fire.

Seasonal variation was only significant within the 5th cm section of leaf bases from Stem 2. This stem displayed a summer/autumn peak in the concentration of Cu. As no other results corroborate this pattern no general conclusions can be drawn. The significant interaction within the 5th cm section of leaf bases from Stem 1 is due to the large peak at the time of fire increasing the overall summer/autumn mean.

4.4.8 Iron

The concentration of Fe displayed no consistent pattern of change over time. No effect from fire was apparent within either cm section of the leaf bases from Stem 1 nor Stem 2. The only pattern of variation displayed by Fe was a winter/spring peak in concentration. This trend was determined significant within the 5th cm section samples from Stem 2. This may again be attributed to the cyclic pattern of wetting and drying reported within Tomkins et al. (1991) to increase nutrient availability. It is suggested that the high variability of Fe may be attributed to dust contamination from the highly lateritic soils present at all three sites.

4.4.9 Manganese

The maximum 1st cm section Mn concentrations were recorded in the youngest leaf bases sampled from all three stems. However, the concentrations within the 5th cm section peaked in the oldest leaf bases sampled. Therefore, no inferences can be made due to the contradictions within the data. The highest Mn concentrations were recorded within the leaf bases from Stem 2, the lowest within Stem 3. The between site soil comparisons do not follow this trend. The concentration of Mn within the soils from the three sites followed the order Amphion (Site 3) > Poison Gully (Site 2) > Gyngoorda (Site 1), with all between site differences being significantly different. It is important to note that the soil analysis results represent the levels of nutrients for a very restricted period of time - they were collected simply to provide a general idea of scale differences between sites. High levels of variation in the concentration of Mn between and within species on different soils have previously been recorded by

O'Connell et al. (1978); environmental conditions such as moisture levels and aeration were suggested as possible causes.

The concentration of Mn within the leaf bases was significantly greater at the time of fire. The nutrient differences recorded at time zero must relate directly to the effect of combustion and therefore leaf death. The peak in Mn concentration at the time of fire in Stem 1 is the consequence of high levels being trapped upon premature leaf death. Under normal circumstances moderate levels of Mn would be retranslocated upon leaf senescence (O'Connell et al. 1978). It is suggested that as the leaf had no opportunity to senesce, no retranslocation occurred and the elevated foliar Mn levels were retained.

After the initial peak the Stem 1 Mn concentrations quickly dropped. However, in Stem 2, the elevated levels were retained for a longer period. A quick drop in the concentration of Mn followed by a period of lower than normal Mn concentrations would be expected after the passage of fire. The post-fire increase in pH and Ca availability would interfere with the absorption of Mn. Mn is immobile at pH 6 or more, when the root must obtain it by reducing MnO_2 (Attwill and Leeper 1987), and excess Mn within the soil is made insoluble by Ca (Ahlgren and Ahlgren 1960). The sustained concentrations in Stem 2 could be explained by the grasstree roots being able to fix the elevated Mn levels, which suggests that the concentration of Ca may be less dominating within the soils from Site 2. This is supported when the site soil concentrations are considered, the levels of Ca are lowest within Site 2. No significant fire effect was recorded within the 5th cm section of leaf bases.

The winter/spring concentrations of Mn were greater than the summer/autumn concentrations within the 5th cm section of leaf bases from all 3 stems. This difference was significant within Stem 2 and Stem 3. These seasonal changes are attributed to the annual cycles of drying and wetting reported by Tomkins et al. (1991). The significant level of interaction recorded within the 1st cm section of Stem 1 can be attributed to the large peak in Mn seen at the time of fire. This peak, a result of fire, increased the overall summer/autumn means interfering with the seasonal analysis.

4.4.10 Sodium

The concentration of Na did not reliably fluctuate above trace levels within any of the 3 stems analysed. No significant difference in the concentration of Na was seen within the soils from all 3 sites. A number of processes may be contributing to the low levels of foliar Na. Na has been reported as being highly mobile within plant tissues, therefore upon leaf senescence substantial amounts of Na are retranslocated from the leaf. In forests of *Eucalyptus obliqua* L'Hérit., about 50% of the Na is withdrawn prior to litter fall (Attiwill 1968). Leaching of Na from the green leaves and the remnant leaf bases will also lead to reduced concentrations. Due to the high mobility of Na it is susceptible to large losses in throughfall. Of the total weight of nutrients cycled in litter and leachate, about 60% of the Na is transferred in canopy leachate (O'Connell et al. 1979).

The availability of Na within the soil normally increases after the passage of fire. Grove et al. (1986) recorded percentage increases over pre-burn concentrations, averaged across all sites, of 100% for extractable Na. Several factors may be interfering in the uptake of Na, leading to reduced foliar levels. One of these factors is the rapid leaching or erosion of Na from the soil - this provides roots with insufficient time to exploit the elevated Na availability. Na released by combustion of plants is very soluble and is leached down the profile or carried away by surface runoff (Trabaud 1983). Competition with other nutrients for sorption sites would also lead to reduced uptake. Fried and Broeshart (1967) found that Na accumulation is inhibited by the presence of all cations tested (Li, K, NH_4 and Ca) at the equivalent concentrations to Na. Attiwill and Leeper (1987) recorded Ca > Mg > K > Na as the order of nutrient competing power when present in equivalent amounts.

4.4.11 Zinc

Stem 1 displayed a lower concentration of Zn within the oldest leaf bases. It is suggested that this trend is linked to leaching of Zn from the leaf bases over time. The older leaf bases have been exposed to leaching for a longer period of time, so that their concentrations are lower than the younger less weathered leaf bases. The highest concentrations of Zn were recorded within Stem 1, while Stem 2 and Stem 3 had equivalent concentrations. This difference cannot be explained by variations in the Zn concentration of the substrate at the three sites. The concentration of Zn was significantly greater within the soils from Amphion (Site 3), yet the stem from this site displayed the lower range of Zn concentrations.

The concentration of Zn within the leaf bases from Stem 1 and Stem 2 dropped at the time of fire. This is due to the premature cessation of Zn deposition within the leaves that are killed by fire. Under normal circumstances the concentration of Zn increases throughout the life-cycle of leaves. As little Zn is mobilised from the leaf prior to senescence (Bowen 1981), the levels of Zn within the remnant leaf bases reflects the levels accumulated within the mature leaf. Therefore, the leaf bases that were not killed by fire reflect the maximum Zn levels attained. The leaf bases that were killed prematurely by fire reflect the amount of Zn that they had accumulated up to the time of their death. If these burnt leaves were able to complete their life cycle undisturbed, they would have accumulated Zn concentrations equivalent to those within adjacent leaf bases.

The availability of Zn within the soil is increased by fire (Khanna et al. 1994). This is reflected by the increased concentration of Zn within the leaf bases 0.5 and 1 year after the passage of fire. However, after approximately a year of increased Zn uptake the concentration within the leaf bases from Stem 2 plummets. It is suggested that this is consistent with the time when ash added by the fire mixes with the soil causing an increase in soil pH. Zn availability decreases with increasing pH, and with increasing levels of phosphate because of precipitation as insoluble Zn phosphates (Sutcliffe and

Baker 1974). The peak in the concentration of Zn 4 years after fire may coincide with the restoration of pre-fire pH levels. Zn levels within the soil are likely to still be elevated at this time due to the strength with which the soil holds Zn at higher pH (Attiwill and Leeper 1987).

4.4.12 Nitrogen

The analysis of N was not included in the original proposal for this study as it was believed that the naturally high levels of variation, typical of N, would conceal any trending within the grasstree leaf bases. Fried and Broeshart (1967) considered concentrations of N to fluctuate the most within the soil solution. They attributed this variation to N not being adsorbed by the soil to any appreciable quantity and to the high dependence of N on microbial activity. The high mobility of N within plant tissues (Majer et al. 1992) allows high levels of N to be retranslocated upon leaf senescence. Increased retranslocation would distort the pattern of N variation within the leaf bases, as would typical losses of N in throughfall.

The concentration of N was found to increase markedly up Stem 1 with the maximum concentrations being recorded in the youngest leaf bases sampled. This trend can be accounted for by leaching losses of N over time. As foliage mobile elements, such as N, exist in water-soluble forms or in molecules that are easily converted to mobile forms (Nelson et al. 1995), they are highly susceptible to leaching losses. The oldest leaf bases contain the lowest levels of N as they have been exposed to the most weathering and therefore the highest leaching.

An increase in the availability of N after fire has been widely reported (Stock and Lewis 1986, Bauhus et al. 1993, Overby and Perry 1996), although the amount and duration of the increase is highly variable. The amount of N added in ash is negatively correlated with fire intensity, as the degree of combustion increases, the addition of N decreases. This can be attributed to increased non-particulate loss of N (Hingston 1985). The concentration of N within the grasstree leaf bases increased after the passage of fire, reflecting the increase in N availability within the substrate. This is consistent with Franco-Vizcaino and Sosa-Ramirez (1997) and Grove et al. (1980) who both reported increased post-burn foliar N levels. The elevated foliar levels of N were relatively short-lived - this is attributed to rapid leaching of N from the soil (Juo and Manu 1996).

4.4.13 Nutrient Trends Summary

Nutrient concentrations within the grasstree leaf bases varied between and within the three stems studied. Table 4-38 has been included so that the general trends for each nutrient over time, and in response to both fire and season are emphasised. A consistent downward trend in the concentration of K, S, Zn and N was revealed over time. The highest concentrations for these nutrients were revealed in the youngest leaf bases sampled. Overall the concentration of Ca was relatively constant, the exception being a slight increase in the youngest leaf bases within the 1st cm section of leaf bases from Stem 1. Ca, Mg and Zn concentrations within the 1st cm section of leaf bases displayed a significant drop in concentration at the time of fire. After this initial fall the concentrations of Ca and Zn increased, culminating in a peak immediately after the fire. The fire-induced Mg concentration drop was sustained for longer and a slow recovery to pre-fire levels was revealed. In contrast, Mn concentrations within the 1st cm section showed a significant increase at the time of fire followed by a decrease to pre-fire levels. A significant winter/spring peak in the concentrations of Ca, Mg, B, Fe and Mn was revealed in the 5th cm section of leaf bases. S and Cu displayed a significant summer/autumn peak. The statistical significance of variations in the concentration of N were not determined as inadequate data were available. The N content of the 5th cm section of leaf bases was not analysed.

Table 4-38. Summary of the variation in nutrient concentrations within both sections of *X. preissii* leaf bases over time, and in response to fire and season. NS, trend not significant * $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$

Nutrient	Trend over 50 years		Fire effect (first summer)		Fire effect (first winter)		Seasonal effect (peak)	
	1st cm	5th cm	1st cm	5th cm	1st cm	5th cm	1st cm	5th cm
Ca	constant	constant	down ***	nil	up ***	nil	winter/spring **	winter/spring ***
K	downward	downward	nil	nil	up NS	up NS	nil	nil
Mg	erratic	erratic	down ***	down **	nil	up **	winter/spring NS	winter/spring ***
S	downward	downward	nil	up **	up NS	down **	summer/autumn *	summer/autumn ***
B	downward	upward	nil	down NS	up NS	up NS	summer/autumn *	winter/spring **
Cu	erratic	constant	nil	up **	up NS	down **	nil	summer/autumn **
Fe	erratic	erratic	nil	down NS	nil	nil	nil	winter/spring *
Mn	downward	upward	up ***	nil	down ***	nil	nil	winter/spring ***
Zn	downward	downward	down *	down *	up *	up *	nil	nil
N	downward	-	nil	-	up	-	summer/autumn	-

5. GENERAL DISCUSSION

As the grasstree ageing technique was validated within the first section of this study, it could be employed to determine the long-term pattern of nutrient changes within the remnant leaf bases in the next section. The seasonal formation of the leaves and the presence of black bands indicating the passage of fire, enabled the nutrient variation in relation to both fire and season to be identified. The success of this approach was nutrient specific and is described below.

Analysis of leaf base concentrations of P using this technique proved unsuccessful. This is predominantly due to the naturally low levels of P cycled within the jarrah forest environment. Other factors include P volatilisation during combustion, the fixing strength of the soil, erosional losses, and the high levels of P retranslocation and throughfall from leaf base tissues.

The concentrations of Ca within the grasstree leaf bases are thought to be a reliable insight into past cycling due to the behaviour of the element within tissues. Upon deposition within the leaf Ca is not redistributed (Sutcliffe and Baker 1974), therefore comparative levels of Ca measured now are consistent with those seen in the leaf when it was living. Ca is also relatively resistant to leaching so that the concentration of Ca has not been substantially depleted over time due to weathering. A distinct increase after the passage of fire and a definite winter/spring peak in assimilation was revealed within the Ca concentrations of grasstree leaf bases making it a useful element for monitoring nutrient cycling changes over time.

The suitability of this technique for monitoring long-term cycling of K is questionable. The concentration of K is highly variable within the life-span of the leaves and it decreases with time after leaf senescence. O'Connell et al. (1978) recorded 50% withdrawal of K from senescing marri and jarrah leaves prior to litter fall. This retranslocation of K and the characteristically high levels of leaching would alter the pattern of variation seen along the length of the grasstree stems. Therefore, the older leaf bases are thought to possess an unreliable record of K variation.

Mg was considered a promising nutrient to implement this technique with. This is due to low levels of Mg retranslocation from the leaf (O'Connell et al. 1978), moderate levels of throughfall (Adams and Attiwill 1986) and low levels of leaching from the soil (Richards and Charley 1983). The first two factors combine to preserve the pattern of Mg variation within the leaf bases, while the last would ensure that plant roots were able to exploit the elevated Mg levels. However, the presence of Ca interfered with Mg uptake so that the immediate post fire increase in the concentration of Mg within the substrate was not reflected by increased foliar levels. Instead, a post-fire decrease in concentration was revealed within the leaf bases. Although the anticipated fire response of Mg within the leaf bases did not eventuate, the trend that does exist is very informative. The technique was successful in depicting variation of Mg in relation to season (winter/spring peak), general trends over time, and in response to fire.

The variation in the concentration of S along the stem was clearly revealed using this technique. However, it is unknown whether this variation was due to leaching of S after deposition within the leaf bases or due to concentration changes within the environment. The former explanation is the most likely one. No consistent pattern of change in the concentration of S was displayed as a consequence of fire. The only significant effect was a peak in S concentration at the time of fire within the 5th cm section of leaf bases from Stem 1.

The effect of fire on the concentration of B within the leaf bases was not consistent within stems and between the sections analysed. Substantial contradictions in the seasonal trend between sections was also revealed. Therefore, the suitability of B for analysis with this technique is questionable. This is thought to be related to the high levels of natural B variation, as displayed within the long unburnt Stem 3.

As soil concentrations of Cu increase after the passage of fire (Khanna et al. 1994), it was expected that elevated Cu concentrations in the leaf bases would be recorded. Cu is not highly susceptible to leaching from the soil (Attiwill and Leeper 1987), allowing plant roots ample time to fix increased amounts of Cu. Also, once within the leaf bases the pattern of Cu uptake should have been retained due to limited levels of retranslocation (Bowen 1981) and throughfall (O'Connell et al. 1978). However, high variability in the concentration of Cu was revealed. It is suggested that this is due to interference in the uptake of Cu, as previously described. The applicability of this technique in determining long term trending of Cu in relation to fire and season is therefore dubious.

Due to high levels of Fe variability within the environment and within the leaf bases no general trend over time nor in relation to fire was revealed. A significant winter/spring maximum in concentration was seen within the 5th cm section of Stem 2; however, this was not supported by the remaining stems. It is likely that high levels of contamination from the lateritic soils contributed considerably to the substantial levels of Fe variation. Therefore, it is concluded that the application of this technique for determining long-term cycling of Fe is inappropriate in sites with lateritic associations.

The effects of fire and season on the foliar concentration of Mn within grasstree leaf bases was clearly defined. The partial mobility of Mn within plant tissues (Sutcliffe and Baker 1974) and limited levels of retranslocation (O'Connell et al. 1978) acted to retain the pattern of Mn concentrations along the grasstree stem. The concentration of Mn peaked at the time of fire, and the duration of this peak varied between stems. A winter/spring maximum in concentration was determined to exist within all 3 stems. Long-term cycling patterns of Mn within the grasstree leaf bases were successfully revealed using this technique.

Na is not a suitable nutrient for this technique. It would be expected that a short-lived post-fire increase and a seasonal pattern of variation in the concentration of Na would have been revealed within the grasstree leaf bases. However, neither of these trends existed due to the overall low concentration of Na within the leaf bases. It is suggested that the low foliar concentrations are the result of naturally low levels in jarrah forest, rapid soil leaching, restricted Na uptake by the root, high levels of retranslocation and significant throughfall from the leaf bases over time.

The effect of fire on the Zn concentrations within grasstree leaf bases was successfully revealed using this technique. A low Zn level existed within the grasstree leaf bases at the time of fire. This was succeeded by a limited increase in Zn concentration within the immediate post-burn period. The fact that Zn did not display the expected sustained increase in post-fire concentrations is an interesting observation. The lack of variation in the Zn levels within Stem 3 provided a distinct contrast with the variations in Stem 1 and Stem 2. The clarity of the Zn concentration changes is attributed to the low mobility of Zn within plant tissues (Sutcliffe and Baker 1974), low levels of Zn retranslocation (Bowen 1981), and limited losses of Zn in throughfall.

No trend in the concentration of N within the grasstree leaf bases was expected to be revealed within this study. This is due to the typically high levels of natural N variation, high soil leaching of N, high percentage volatilisation, high levels of retranslocation and the readiness with which it is leached from leaves. The limited sample of leaf bases analysed clearly demonstrated an increase in the concentration of N within the immediate post-fire environment. Future studies should include N within their nutrient analysis routine so that the influence of fire can be statistically assessed.

Trends in the concentrations of nutrients were found to vary between the 1st and 5th cm sections within the same leaf base. For example, the Ca concentration within the 1st cm section displayed a distinct fire effect, yet the 5th cm section exhibited only seasonal variation. The physiology behind this observation has yet to be satisfactorily explained. It was suggested that nutrients may be more susceptible to leaching within the 5th cm section than the 1st, as a concentration gradient existed along the leaf base with the lowest concentrations in the exterior section. However, if this is the case, then why is the seasonal effect not leached out from the 5th cm section with the fire effect? The difference may be the result of anatomical variations between the two leaf base sections. Research endeavouring to solve these questions is presently underway. As part of a proposed PhD project, long-term studies on the variation of nutrient deposition and mobilisation along the entire length of living grasstree leaves throughout their life-span will be made. A project involving the sectioning of *X. preissii* leaf bases has been commenced to determine any anatomical variation or depositional differences. Hopefully, these efforts will reveal the causes behind this unusual observation.

The historical fire frequency results indicate a general decrease in the frequency of fire since European colonisation. It is suggested that this decrease in fire frequency may be increasing the total nutrient budget within the jarrah forest, due to a reduction in the nutrient losses associated with fire. A general decrease in the concentration of Ca, K, S, B, Cu, Mn, Zn and N within grasstree leaf bases was recorded through time, peaking in the youngest leaf base samples. The obvious explanation for such a trend is leaching of nutrients from the remnant leaf bases. This explanation is satisfactory when the more mobile nutrients are considered, eg K, S and N. However, in the case of the less mobile nutrients, such as Ca, Mg, B, Cu, Mn and Zn, that are less susceptible to leaching, this explanation is unsatisfactory.

These increases in concentration in the youngest leaf bases could also be accounted for by an increase in the total amount of nutrients within the system, due to less frequent losses of nutrients during burning. Large amounts of nutrients are lost through volatilisation, leaching and particulate movement as a result of fire (Hingston 1985). A post-fire increase in the level of available nutrients may be recorded. However, these increases are short-lived and they come at a net loss to the total nutrient budget. Raison et al. (1985b) stated that prescribed fire rotations of 12 years are necessary to allow natural inputs to replace losses of N to the atmosphere in a single fire event, and 20 years to replace losses of P. Hall (1994) suggested that the short-term protection afforded by fuel reduction burning may come at a long-term loss to productivity as the soil of a forest ecosystem is a principal component.

Trabaud (1983) found that Mg values were lower in soils submitted to repeated fires than in unburnt soils and those burnt just once. Upon comparison of the soil analysis results, the concentrations of the majority of nutrients were greater within the Amphion site soils, the site excluded from fire for the last 60 years. The concentrations of EDTA Zn, EDTA Mn, EDTA Fe and extractable Ca were significantly greater at Amphion. Further research is required to determine whether these increased levels of nutrients are directly related to the exclusion of fire or just a site effect. A PhD student is commencing experiments to quantify the degree of leaching of the more immobile nutrients; this will determine whether increasing concentrations within the leaf bases over time can be accounted for by throughfall.

If confirmed, an increase in the total levels of nutrients with a decrease in fire frequency should not be seen as an argument to exclude fire altogether. Fire exclusion has a number of associated problems of its own. In its present state, if a fire was to occur at the Amphion site the huge fuel load would lead to a large conflagration involving widespread incineration and tree deaths. The amounts of nutrients lost through volatilisation during such an event would be high due to the extreme temperatures reached. The post-fire nutrient losses due to erosion and leaching would also be considerable. Total nutrient losses in such an event may be equivalent to those lost in a number of low-intensity prescribed burns.

5.1 CONCLUSIONS AND RECOMMENDATIONS

A new technique for ageing grasstrees and determining historical fire frequency was validated in this study. The growth rates calculated are equivalent with those reported elsewhere using different techniques. Investigations into carbon isotope ratios within the remnant leaf bases and other vegetative structures merits further research to further validate the technique. Such work may reveal important insights into historical growth rates and provide further confirmation of the highly seasonal growth of grasstrees.

Using the banding technique, a downturn in the frequency of fire since European colonisation was calculated within the two northern jarrah forest sites studied. A large scale project determining the historical fire frequencies within varying ecosystems should be implemented throughout the southwest. This would allow broader conclusions to be drawn on the effect of colonisation on burning practices. It is suggested that grasstrees with greater ages than those studied here be sought, so that fire frequencies even further into the past may be calculated. By relating the fire frequency information from grasstrees to differences in vegetation structure and floristic composition, it may be possible to assess how varying fire regimes have shaped the native vegetation of the southwest. Such information is important when devising fire management programs. Implemented fire regimes must be based on a firm understanding of the historical role of fire as well as ecosystem changes likely to be induced by discriminant wildfires or by the exclusion of fire (Burrows 1985).

This technique was successful at portraying long-term variations in a number of foliar nutrients. Limited success was achieved with nutrients that are susceptible to losses in throughfall, are retranslocated in significant amounts and/or naturally demonstrate high levels of variation. The restricted scale of N analysis did reveal patterns of variation within the leaf bases; it is therefore advised that further research be performed on this nutrient. Further replication within and between sites is recommended so that contradictions in the data can be reassessed. It is unknown whether the contradictions reflect random events or site factors.

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APPENDICES

Appendix 1

Chapter 3 - Raw Experimental Data and Statistical Analyses Output

Colorimetric measurements, according to Hunter's *L* , *a* , *b* for Stems 1, 2 and 3.

Reading		Gyngoorda			Poison Gully			Amphion	
number	*L*	*a*	*b*	*L*	*a*	*b*	*L*	*a*	*b*
1	5966	688	1069	6472	108	403	5864	256	736
2	6269	221	1132	6509	119	398	6237	71	963
3	6217	549	1093	6481	202	546	6129	-25	1073
4	5991	643	1468	6271	189	1067	6147	292	989
5	5644	778	1605	6179	225	1172	6035	-46	1227
6	5645	654	1434	6263	120	719	5743	-69	1123
7	5888	778	1135	6356	466	745	6193	42	791
8	6281	476	1185	6484	257	545	6331	-81	862
9	6129	413	1089	6474	70	422	6206	129	811
10	6330	297	1452	6623	134	391	5949	199	1409
11	6079	325	1859	6694	39	467	5638	180	1325
12	5988	236	1109	6458	231	471	5754	186	1123
13	6191	366	1300	6374	276	955	6084	64	1005
14	6164	634	1100	6535	117	562	6030	77	1184
15	6084	485	995	6695	331	248	5915	22	1313
16	6044	535	1343	6727	103	377	5620	152	1699
17	5760	297	1373	6396	93	471	5135	378	1579
18	5633	283	1320	6048	117	617	5186	28	1429
19	5641	325	1272	5522	465	858	5794	-26	869
20	6047	390	917	5599	111	710	6020	44	1088
21	6341	445	979	5714	346	589	5854	251	1196
22	6339	354	1088	5753	282	1042	5476	79	1749
23	5966	424	1340	5676	302	898	5054	444	1470
24	5883	657	1327	6221	209	498	4926	138	1481
25	5617	698	1197	6374	48	700	5143	236	1260
26	5670	733	1130	6263	300	526	5325	228	856
27	6255	282	1037	6108	-110	1257	5426	485	1082
28	6506	77	1304	5793	189	654	5288	207	1358
29	6427	288	1235	5748	39	1195	5175	70	1475
30	6419	100	1555	5692	373	967	5269	303	1020
31	5630	773	1459	5810	244	997	5382	76	1175
32	5968	773	971	5569	-80	1029	5461	-33	1411
33	6417	367	1068	5524	402	419	5397	170	1712
34	6547	434	895	5809	410	661	5122	300	1697
35	6564	315	1365	5650	161	1115	5048	109	1536
36	6101	370	1516	5518	196	902	5300	-54	1351
37	5902	517	1666	5566	129	1192	5674	38	1097
38	5837	71	1066	5680	138	869	5729	146	1501
39	6585	285	978	6063	201	557	5355	-51	1745
40	6151	399	1624	6023	-2	979	4877	260	1716
41	6313	250	1583	5793	-39	1226	4764	430	1633
42	5745	706	1812	5212	195	1231	4851	296	1464
43	5392	706	1496	4984	340	1007	5026	177	1309
44	6092	718	1287	5149	445	950	5369	51	812
45	6362	498	1488	5473	-354	1019	5458	160	1112
46	6120	625	1901	5707	375	822	5475	163	1333
47	5617	906	1774	6072	334	578	5527	157	1407
48	5528	938	1724	6209	117	999	5250	119	1513
49	5253	885	1386	5653	621	1243	5173	173	1286
50	5543	799	1209	4950	711	1303	5128	6	1270
51	6147	421	1276	5010	326	1066	5120	-39	1304
52	6053	662	1417	5440	439	1049	5202	-14	1481
53	5606	440	1945	5712	109	1169	5096	125	1265
54	5109	534	1519	5707	462	997	4950	-152	1519
55	5257	602	1043	5902	215	429	4684	202	1230
56	5676	469	952	6009	99	789	4837	-81	1293
57	6368	282	1005	5943	355	590	4704	-228	1099
58	6476	289	1336	5729	99	1002	4720	1	1143
59	6366	283	1436	5465	227	575	4647	83	1250
60	6164	459	1522	5797	-80	1029	4423	244	1594
61	5687	462	1340	5986	85	492	4233	-34	1501
62	5502	355	1190	6231	143	291	4314	-120	1075
63	6016	541	687	6238	-45	332	4557	-109	962
64	6530	286	792	6107	204	602	4792	-92	1104
65	6693	28	1072	5688	163	928	4643	-129	1320
66	6332	129	1277	5544	132	766	4302	91	1384
67	6201	198	1057	5440	460	665	4125	41	1432
68	6374	853	853	5192	720	95	4109	93	1200

Stem fluctuation and colour band correlation raw data for all 3 stems.

Reading	Gyngoorda		Poison Gully		Amphion	
Number	Band colour	Peak/Trough	Band colour	Peak/Trough	Band colour	Peak/Trough
1	White	Peak	White	Peak	White	Trough
2	Brown	Trough	Brown	Trough	Brown	Peak
3	White	Peak	White	Peak	White	Trough
4	Brown	Trough	Brown	Trough	Brown	Peak
5	White	Peak	White	Peak	White	Trough
6	Brown	Trough	Brown	Incline	Brown	Peak
7	White	Peak	White	Peak	White	Trough
8	Brown	Trough	Brown	Trough	Brown	Peak
9	White	Peak	White	Peak	White	Trough
10	Brown	Trough	Brown	Trough	Brown	Peak
11	White	Trough	White	Peak	White	Peak
12	White	Peak	Brown	Peak	Brown	Trough
13	Brown	Trough	White	Peak	White	Trough
14	White	Peak	Brown	Trough	Brown	Peak
15	Brown	Trough	White	Peak	White	Trough
16	White	Peak	Brown	Trough	Brown	Peak
17	Brown	Trough	White	Trough	White	Trough
18	White	Incline	Brown	Trough	Brown	Peak
19	Brown	Incline	White	Peak	White	Trough
20	White	Incline	Brown	Trough	Brown	Peak
21	Brown	Incline	White	Peak	White	Trough
22	Brown	Trough	Brown	Trough	Brown	Peak
23	White	Peak	White	Peak	White	Trough
24	Brown	Trough	Brown	Trough	Brown	Peak
25	White	Peak	White	Peak	White	Trough
26	Brown	Trough	Brown	Trough	Brown	Peak
27	White	Peak	White	Peak	White	Trough
28	Brown	Trough	Brown	Trough		
29	White	Peak	White	Peak		
30	Brown	Trough	Brown	Trough		
31	White	Peak	White	Peak		
32	Brown	Trough	Brown	Trough		
33	White	Peak	White	Peak		
34			Brown	Trough		
35			White	Incline		
36			Brown	Peak		
37			White	Incline		
38			Brown	Trough		
39			White	Peak		
40			Brown	Trough		

Correlation of stem fluctuations and coloured bands chi-square test output.

Gyngoorda Stem

Summary Table for Rows, Columns

Num. Missing	0
DF	2
Chi Square	25.260
Chi Square P-Value	<.0001
G-Squared	•
G-Squared P-Value	•
Contingency Coef.	.658
Cramer's V	.875

Observed Frequencies for Rows, Columns

	Column 1	Column 2	Column 3	Totals
Row 1	14	1	2	17
Row 2	0	14	2	16
Totals	14	15	4	33

Poison Gully Stem

Summary Table for Rows, Columns

Num. Missing	0
DF	2
Chi Square	26.398
Chi Square P-Value	<.0001
G-Squared	31.122
G-Squared P-Value	<.0001
Contingency Coef.	.631
Cramer's V	.812

Observed Frequencies for Rows, Columns

	Column 1	Column 2	Column 3	Totals
Row 1	17	1	2	20
Row 2	2	17	1	20
Totals	19	18	3	40

Amphion Stem

Summary Table for Rows, Columns

Num. Missing	0
DF	1
Chi Square	19.583
Chi Square P-Value	<.0001
G-Squared	23.137
G-Squared P-Value	<.0001
Contingency Coef.	.648
Phi	.852
Cty. Cor. Chi Square	16.436
Cty. Cor. P-Value	<.0001
Fisher's Exact P-Value	<.0001

Observed Frequencies for Rows, Columns

	Column 1	Column 2	Totals
Row 1	1	13	14
Row 2	12	1	13
Totals	13	14	27

Stem fluctuation and colour band correlation raw data measurements.

Stem	Peak to peak (cm)	White to white (cm)
Gyngoorda	1.727	1.616
	1.323	1.34
	1.421	1.553
	1.743	1.887
	1.987	2.151
	1.505	1.679
	1.239	1.03
	1.054	1.098
	1.59	1.575
	1.539	1.617
	1.205	1.396
	1.163	1.169
	1.1	1.257
	1.069	1.141
	1.631	1.236
	1.416	1.263
Mean	1.420	1.438
St. Deviation	0.274	0.308
Poison Gully	2.067	2.129
	1.811	1.779
	1.716	1.85
	1.839	2.074
	1.511	1.643
	1.987	1.962
	2.049	2.037
	1.836	1.688
	2.071	2.1
	1.66	1.823
	2.121	2.05
	2.059	2.248
	1.618	1.775
	2.425	2.327
	1.778	1.973
Mean	1.903	1.964
St. Deviation	0.237	0.201
Amphion	2.549	2.827
	2.353	2.099
	2.694	2.735
	2.302	2.629
	2.489	2.661
	2.731	2.145
	2.654	2.625
	2.591	2.571
	2.781	2.587
	2.437	2.659
	2.571	2.807
	2.489	2.604
	2.45	2.347
	2.88	2.859
	2.497	2.821
	2.487	2.585
	2.863	2.756
	2.7	2.658
	2.598	2.741
	2.394	2.451
Mean	2.576	2.608
St. Deviation	0.162	0.209

Paired t-test output. Testing the correlation between the stem fluctuations and coloured bands. (1 - Stem 1, 2 - Stem 2, 3 - Stem 3)

```
                 Number of             2-tail
Variable           pairs        Corr   Sig          Mean          SD     SE of Mean
-----------------------------------------------------------------------------------
PEAK1                                             1.4195        .274           .069
                    16          .849    .000
WHITE1                                            1.4380        .308           .077
-----------------------------------------------------------------------------------


          Paired Differences          |
   Mean            SD      SE of Mean |       t-value            df     2-tail Sig
--------------------------------------|--------------------------------------------
  -.0185          .163           .041 |        -.45              15           .657
95% CI (-.106,  .069)                 |


                 Number of             2-tail
Variable           pairs        Corr   Sig          Mean          SD     SE of Mean
-----------------------------------------------------------------------------------
PEAK2                                             1.9032        .237           .061
                    15          .862    .000
WHITE2                                            1.9639        .201           .052
-----------------------------------------------------------------------------------


          Paired Differences          |
   Mean            SD      SE of Mean |       t-value            df     2-tail Sig
--------------------------------------|--------------------------------------------
  -.0607          .121           .031 |       -1.95              14           .072
95% CI (-.127,  .006)                 |


                 Number of             2-tail
Variable           pairs        Corr   Sig          Mean          SD     SE of Mean
-----------------------------------------------------------------------------------
PEAK3                                             2.5755        .162           .036
                    20          .316    .174
WHITE3                                            2.6083        .209           .047
-----------------------------------------------------------------------------------


          Paired Differences          |
   Mean            SD      SE of Mean |       t-value            df     2-tail Sig
--------------------------------------|--------------------------------------------
  -.0328          .220           .049 |        -.67              19           .513
95% CI (-.136,  .070)                 |
```

Appendix 2

Lacquer Thinner Experiment - Raw Data and Statistical Analysis Output

Gyngoorda stem (Stem 1) - Lacquer thinner experiment raw data.

Year	cm section	Preparation method	P (ICP) %db	K (ICP) %db	Ca (ICP) %db	Mg (ICP) %db	Na (ICP) %db	S (ICP) %db	B (ICP) mg/kg	Cu (ICP) mg/kg	Fe (ICP) mg/kg	Mn (ICP) mg/kg	Zn (ICP) mg/kg
1943	1	lacquer cleaned	<0.01	0.05	0.39	0.08	<0.01	0.05	5	3.7	22	5.1	15
1943/44	1	lacquer cleaned	<0.01	0.03	0.32	0.08	<0.01	0.04	4	2.5	8	5.8	7.1
1944	1	lacquer cleaned	<0.01	0.04	0.52	0.03	<0.01	0.05	5	3.6	20	4.1	39.5
1944/45	1	lacquer cleaned	<0.01	0.05	0.49	0.04	<0.01	0.05	4	4.8	19	4.7	29.5
1945	1	lacquer cleaned	<0.01	0.06	0.5	0.05	0.01	0.05	5	3.1	8	4.4	27.7
1943	1	melted off	<0.01	0.02	0.37	0.1	<0.01	0.04	5	3.2	15	5.4	123.2
1943/44	1	melted off	<0.01	0.02	0.3	0.09	<0.01	0.04	4	3.3	23	7	64.8
1944	1	melted off	<0.01	0.04	0.54	0.03	0.01	0.05	5	3.8	23	4.1	51.4
1944/45	1	melted off	<0.01	0.06	0.48	0.03	<0.01	0.05	5	2.9	8	4.2	23.2
1945	1	melted off	<0.01	0.06	0.52	0.04	0.01	0.05	6	3.4	24	4.5	31.9
1943	1	resin left on	<0.01	0.02	0.27	0.06	<0.01	0.04	3	2	10	3.2	31.6
1943/44	1	resin left on	<0.01	0.01	0.18	0.05	<0.01	0.02	3	1.9	12	4	33
1944	1	resin left on	<0.01	0.02	0.32	0.02	<0.01	0.03	3	2	6	2.2	26.4
1944/45	1	resin left on	<0.01	0.04	0.32	0.02	<0.01	0.04	3	2.3	4	2.8	28.6
1945	1	resin left on	<0.01	0.05	0.33	0.03	<0.01	0.04	4	2.3	10	3.1	28.1
1943	5	lacquer cleaned	<0.01	0.03	0.12	0.13	0.02	0.02	3	1.5	28	3.3	20.7
1943/44	5	lacquer cleaned	<0.01	0.03	0.1	0.13	0.01	0.03	2	1.5	15	3.8	7.7
1944	5	lacquer cleaned	<0.01	0.04	0.11	0.16	0.02	0.03	4	1.5	35	5	30.8
1944/45	5	lacquer cleaned	<0.01	0.04	0.07	0.22	0.02	0.02	3	1.3	22	3.1	21.9
1945	5	lacquer cleaned	<0.01	0.04	0.12	0.2	0.02	0.03	4	1.5	50	6.2	27
1943	5	melted off	<0.01	0.03	0.11	0.12	0.02	0.02	3	2.2	52	4.6	66.1
1943/44	5	melted off	<0.01	0.03	0.09	0.13	0.01	0.02	2	3.1	39	5.1	13.8
1944	5	melted off	<0.01	0.05	0.11	0.15	0.03	0.02	4	1.2	23	4.2	21.6
1944/45	5	melted off	0.01	0.05	0.08	0.24	0.02	0.02	3	1.9	81	4.9	33.6
1945	5	melted off	<0.01	0.03	0.11	0.22	0.02	0.02	3	1.7	37	4.6	41.9
1943	5	resin left on	<0.01	0.02	0.12	0.14	0.01	0.02	3	1	21	3.1	20.2
1943/44	5	resin left on	<0.01	0.04	0.09	0.12	0.01	0.03	2	1.5	14	4.9	27
1944	5	resin left on	<0.01	0.04	0.11	0.13	0.02	0.02	4	1	12	3.9	29.4
1944/45	5	resin left on	<0.01	0.05	0.08	0.23	0.02	0.02	4	1	16	3.6	22.1
1945	5	resin left on	<0.01	0.03	0.12	0.22	0.02	0.02	3	0.8	15	4.1	37

Gyngoorda stem, 1st cm - Lacquer thinner experiment one-way analysis of variance and Duncan's new multiple range test output.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	.001	4.200E-4	1.575	.2470
Residual	12	.003	2.667E-4		

Dependent: K

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	.084	.042	5.778	.0175
Residual	12	.088	.007		

Dependent: Ca

Duncan New Multiple Range
Effect: Codes
Dependent: Ca
Significance level: .05

	Count	Mean
Resin left	5	.284
Melted	5	.442
Lacquer	5	.444

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	.001	.001	1.094	.3662
Residual	12	.008	.001		

Dependent: Mg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	.001	2.867E-4	6.615	.0116
Residual	12	.001	4.333E-5		

Dependent: S

Duncan New Multiple Range
Effect: Codes
Dependent: S
Significance level: .05

	Count	Mean
Resin left	5	.034
Melted	5	.046
Lacquer	5	.048

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	8.933	4.467	13.400	.0009
Residual	12	4.000	.333		

Dependent: B

Duncan New Multiple Range
Effect: Codes
Dependent: B
Significance level: .05

	Count	Mean
Resin left	5	3.200
Lacquer	5	4.600
Melted	5	5.000

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	6.017	3.009	10.435	.0024
Residual	12	3.460	.288		

Dependent: Cu

Duncan New Multiple Range
Effect: Codes
Dependent: Cu
Significance level: .05

	Count	Mean
Resin left	5	2.100
Melted	5	3.320
Lacquer	5	3.540

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	272.133	136.067	3.855	.0509
Residual	12	423.600	35.300		

Dependent: Fe

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	11.777	5.889	7.588	.0074
Residual	12	9.312	.776		

Dependent: Mn

Duncan New Multiple Range
Effect: Codes
Dependent: Mn
Significance level: .05

	Count	Mean
Resin left	5	3.060
Lacquer	5	4.820
Melted	5	5.040

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	3550.396	1775.198	3.083	.0831
Residual	12	6908.584	575.715		

Dependent: Zn

Gyngoorda stem, 5th cm - Laquer thinner experiment one-way analysis of variance and Duncan's new multiple range test output.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	1.333E-5	6.667E-6	.071	.9315
Residual	12	.001	9.333E-5		

Dependent: K

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	5.333E-5	2.667E-5	.083	.9206
Residual	12	.004	3.200E-4		

Dependent: Ca

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	5.333E-5	2.667E-5	.011	.9893
Residual	12	.030	.002		

Dependent: Mg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	9.333E-5	4.667E-5	2.800	.1005
Residual	12	2.000E-4	1.667E-5		

Dependent: S

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	.133	.067	.105	.9009
Residual	12	7.600	.633		

Dependent: B

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	2.325	1.163	6.087	.0150
Residual	12	2.292	.191		

Dependent: Cu

Duncan New Multiple Range
Effect: Codes
Dependent: Cu
Significance level: .05

	Count	Mean
Resin left on	5	1.060
Lacquer	5	1.460
Melted off	5	2.020

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	2374.933	1187.467	5.312	.0223
Residual	12	2682.400	223.533		

Dependent: Fe

Duncan New Multiple Range
Effect: Codes
Dependent: Fe
Significance level: .05

	Count	Mean
Resin left on	5	15.600
Lacquer	5	30.000
Melted off	5	46.400

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	1.445	.723	.961	.4101
Residual	12	9.024	.752		

Dependent: Mn

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Codes	2	480.977	240.489	1.356	.2946
Residual	12	2128.800	177.400		

Dependent: Zn

Appendix 3

All 5 cm Leaf Base Sections - Raw Data & Representative Graphs

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1890 to 1903/04.

Year	cm section	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
		%db	%db	%db	%db	%db	%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1890	1	<0.01	0.02	0.52	0.06	<0.01	0.04	4	3.2	20	4.6	26
1890	2	<0.01	0.01	0.19	0.1	<0.01	0.03	4	2	13	4.1	23
1890	3	<0.01	0.01	0.12	0.14	<0.01	0.03	4	1.5	5	3.9	10
1890	4	<0.01	0.01	0.14	0.13	0.01	0.02	4	1.1	7	4.8	8.4
1890	5	<0.01	0.02	0.16	0.08	0.02	0.02	3	1.3	24	6.6	7.3
1890/91	1	<0.01	0.02	0.5	0.05	<0.01	0.04	4	3.6	12	4	15
1890/91	2	<0.01	0.02	0.13	0.11	<0.01	0.03	4	1.9	26	4	33
1890/91	3	<0.01	0.01	0.09	0.15	0.01	0.03	4	1.2	14	3.6	13
1890/91	4	<0.01	0.01	0.09	0.18	0.01	0.02	4	1.1	13	4.6	13
1890/91	5	<0.01	0.02	0.12	0.12	0.01	0.02	4	1.2	28	5.8	12
1891	1	<0.01	0.02	0.53	0.07	<0.01	0.04	5	3.5	61	4.6	28
1891	2	<0.01	0.01	0.19	0.12	<0.01	0.03	4	2.2	19	4	28
1891	3	<0.01	<0.01	0.14	0.17	<0.01	0.02	4	2.1	42	3.7	32
1891	4	<0.01	<0.01	0.12	0.18	<0.01	0.02	4	1.3	36	3.7	27
1891	5	<0.01	0.01	0.12	0.13	0.01	0.02	4	1.4	120	5.9	20
1891/92	1	<0.01	0.01	0.52	0.09	<0.01	0.03	5	2.7	18	4.3	19
1891/92	2	<0.01	<0.01	0.18	0.13	<0.01	0.04	4	1.7	13	3.9	17
1891/92	3	<0.01	<0.01	0.12	0.15	<0.01	0.02	4	1.3	17	3	18
1891/92	4	<0.01	<0.01	0.11	0.17	<0.01	0.02	4	0.9	24	3.2	17
1891/92	5	<0.01	0.01	0.12	0.1	<0.01	0.02	4	0.8	27	5.2	12
1892	1	<0.01	0.01	0.57	0.13	<0.01	0.03	4	2.3	25	3.6	13
1892	2	<0.01	<0.01	0.23	0.15	<0.01	0.03	3	1.6	27	2.8	15
1892	3	<0.01	<0.01	0.16	0.13	<0.01	0.03	3	4.9	200	3.7	51
1892	4	<0.01	<0.01	0.17	0.13	<0.01	0.02	4	2	53	3.2	24
1892	5	<0.01	0.01	0.13	0.08	0.01	0.01	3	4.1	1200	15	54
1892/93	1	<0.01	0.01	0.44	0.12	<0.01	0.04	5	2.4	38	6.3	13
1892/93	2	<0.01	<0.01	0.21	0.14	<0.01	0.04	4	1.6	21	6	24
1892/93	3	<0.01	0.01	0.15	0.12	<0.01	0.03	3	1.1	15	4.8	11
1892/93	4	<0.01	<0.01	0.12	0.12	<0.01	0.02	3	1	6	3.8	1.2
1892/93	5	<0.01	0.01	0.12	0.11	<0.01	0.02	3	1.5	14	4.4	1.8
1893	1	<0.01	0.02	0.48	0.08	<0.01	0.04	6	3	12	5.4	12
1893	2	<0.01	0.02	0.19	0.11	<0.01	0.04	5	2.6	19	5.2	18
1893	3	<0.01	0.01	0.14	0.14	<0.01	0.03	5	2.4	28	5.2	39
1893	4	<0.01	0.01	0.13	0.15	<0.01	0.03	5	2.1	32	6.1	46
1893	5	<0.01	0.02	0.14	0.11	<0.01	0.02	4	2.4	52	8.4	35
1893/94	1	<0.01	0.02	0.48	0.06	<0.01	0.03	5	2.9	33	4.7	20
1893/94	2	<0.01	0.01	0.18	0.14	<0.01	0.03	5	2.1	18	4.2	29

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1890 to 1903/04.

1893/94	3	<0.01	<0.01	0.14	0.17	<0.01	0.03	4	1.8	26	4.1	31
1893/94	4	<0.01	0.01	0.13	0.15	<0.01	0.02	5	1.4	46	4.6	24
1893/94	5	<0.01	0.02	0.16	0.09	0.01	0.02	4	3.4	340	9.6	82
1894	1	<0.01	0.02	0.57	0.09	<0.01	0.04	5	2.9	20	4.4	16
1894	2	<0.01	0.01	0.22	0.16	<0.01	0.03	4	2	20	4.8	22
1894	3	<0.01	<0.01	0.17	0.16	<0.01	0.03	4	1.8	15	4	20
1894	4	<0.01	0.01	0.15	0.16	<0.01	0.02	5	2	380	7.1	36
1894	5	<0.01	0.02	0.16	0.12	0.01	0.02	5	2.3	300	9.6	73
1894/95	1	<0.01	0.02	0.62	0.1	<0.01	0.04	5	2.7	15	4.6	15
1894/95	2	<0.01	0.01	0.22	0.16	<0.01	0.03	4	1.9	13	5	20
1894/95	3	<0.01	0.01	0.16	0.16	<0.01	0.03	4	1.7	21	3.9	29
1894/95	4	<0.01	0.01	0.14	0.16	<0.01	0.02	6	1.7	71	5.6	54
1894/95	5	<0.01	0.02	0.15	0.1	0.01	0.02	4	1	55	6	23
1895	1	<0.01	0.01	0.63	0.12	<0.01	0.04	4	2.6	24	4.3	11
1895	2	<0.01	0.01	0.25	0.17	<0.01	0.03	3	1.4	17	3.9	22
1895	3	<0.01	<0.01	0.18	0.15	<0.01	0.03	2	3	9	2.3	14
1895	4	<0.01	0.01	0.17	0.14	0.01	0.02	3	1.7	8	2.3	5.8
1895	5	<0.01	0.01	0.19	0.1	0.02	0.02	3	1.4	38	6	7.9
1895/96	1	<0.01	0.01	0.47	0.13	<0.01	0.04	4	2.4	15	5.4	11
1895/96	2	<0.01	<0.01	0.2	0.16	<0.01	0.03	3	1.2	4	5.3	1.4
1895/96	3	<0.01	0.01	0.17	0.12	<0.01	0.03	2	1.8	32	3.8	2.5
1895/96	4	<0.01	0.01	0.12	0.12	<0.01	0.03	2	1.1	8	3.6	2.6
1895/96	5	<0.01	0.01	0.12	0.12	<0.01	0.02	4	1.5	10	4.3	4.2
1896	1	<0.01	0.02	0.55	0.06	0.01	0.05	6	3	11	4.9	18
1896	2	<0.01	0.01	0.22	0.12	0.01	0.03	4	1.5	9	5.4	18
1896	3	<0.01	0.01	0.16	0.13	0.01	0.03	4	1.1	8	4.8	15
1896	4	<0.01	0.01	0.15	0.15	0.01	0.04	5	1.4	13	5.8	18
1896	5	<0.01	0.02	0.17	0.12	0.01	0.03	4	1.2	16	7.8	18
1896/97	1	<0.01	0.02	0.56	0.06	0.01	0.04	4	2.7	18	4.3	12
1896/97	2	<0.01	0.01	0.17	0.13	0.02	0.04	6	1.8	24	5	19
1896/97	3	<0.01	0.01	0.14	0.16	0.02	0.03	8	1.4	9	5.2	13
1896/97	4	<0.01	0.02	0.14	0.16	0.02	0.03	8	0.9	15	6.6	17
1896/97	5	<0.01	0.02	0.13	0.1	0.02	0.02	5	0.9	22	7	12
1897	1	<0.01	0.01	0.54	0.1	<0.01	0.04	4	2.5	24	4.1	12
1897	2	<0.01	0.01	0.26	0.12	0.01	0.03	4	1.6	12	3.6	8
1897	3	<0.01	0.01	0.18	0.11	<0.01	0.03	4	1.5	9	2.4	7.4
1897	4	<0.01	0.01	0.19	0.13	0.01	0.02	6	1.2	14	4.2	12
1897	5	<0.01	0.02	0.19	0.1	0.02	0.02	5	0.8	27	6.6	16
1897/98	1	<0.01	0.01	0.48	0.1	<0.01	0.04	4	2.2	18	4.1	14
1897/98	2	<0.01	0.01	0.2	0.13	0.01	0.04	3	1.6	29	3.7	9.2

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1890 to 1903/04.

1897/98	3	<0.01	<0.01	0.14	0.13	0.01	0.03	5	1.4	6	2.8	11
1897/98	4	<0.01	0.01	0.15	0.19	0.01	0.03	6	0.9	14	5.1	21
1897/98	5	<0.01	0.02	0.16	0.12	0.02	0.02	5	0.7	25	6.4	11
1898	1	<0.01	0.01	0.54	0.09	<0.01	0.04	4	2	52	3.8	12
1898	2	<0.01	<0.01	0.23	0.13	<0.01	0.03	3	1	4	3.1	2.4
1898	3	<0.01	<0.01	0.17	0.11	<0.01	0.03	3	1.1	10	2.3	6.1
1898	4	<0.01	0.01	0.15	0.14	0.01	0.03	4	1.1	12	3.2	8.3
1898	5	<0.01	0.02	0.16	0.12	0.02	0.02	3	1.2	31	5.7	14
1898/99	1	<0.01	0.01	0.56	0.11	<0.01	0.04	4	2.6	14	3.9	9.9
1898/99	2	<0.01	0.01	0.23	0.14	<0.01	0.03	3	1.3	20	3.4	15
1898/99	3	<0.01	<0.01	0.17	0.12	0.01	0.03	2	1.3	9	2.4	11
1898/99	4	<0.01	<0.01	0.16	0.13	0.01	0.03	3	1.2	15	3	12
1898/99	5	<0.01	0.01	0.14	0.08	0.02	0.02	2	1.4	20	4.4	11
1899	1	<0.01	0.01	0.45	0.11	<0.01	0.04	4	2.2	11	3.8	6.5
1899	2	<0.01	<0.01	0.18	0.14	<0.01	0.03	4	1.3	9	3.1	10
1899	3	<0.01	<0.01	0.13	0.11	<0.01	0.03	2	1.2	11	2.2	7.2
1899	4	<0.01	<0.01	0.13	0.11	<0.01	0.03	3	1.4	2	2	2.2
1899	5	<0.01	0.02	0.16	0.08	0.01	0.02	4	1.7	16	5	11
1899/00	1	<0.01	0.01	0.44	0.1	<0.01	0.04	5	2.2	11	5.5	7.1
1899/00	2	<0.01	0.01	0.21	0.13	<0.01	0.04	5	1.5	11	5.8	9.4
1899/00	3	<0.01	0.01	0.16	0.12	<0.01	0.03	5	1	7	4.9	4.4
1899/00	4	<0.01	0.01	0.12	0.1	<0.01	0.03	4	1	4	3.6	1
1899/00	5	<0.01	0.01	0.13	0.09	0.01	0.03	5	1.4	35	4.5	6.3
1900	1	<0.01	0.02	0.6	0.07	<0.01	0.05	7	2.9	20	5.1	22
1900	2	<0.01	0.01	0.23	0.12	0.01	0.03	6	1.9	19	4.3	17
1900	3	<0.01	0.01	0.17	0.14	0.01	0.03	7	1.8	19	4.4	31
1900	4	<0.01	0.01	0.16	0.12	0.01	0.03	6	1.7	20	5.3	32
1900	5	<0.01	0.01	0.15	0.11	0.02	0.02	6	1.6	7	5.2	17
1900/01	1	<0.01	0.02	0.56	0.06	0.01	0.04	6	2.8	14	4.2	19
1900/01	2	<0.01	0.01	0.18	0.12	0.01	0.03	5	1.9	7	4	20
1900/01	3	<0.01	0.01	0.13	0.13	0.01	0.03	6	1.8	20	3.7	18
1900/01	4	<0.01	0.02	0.13	0.14	0.01	0.02	6	1.4	16	4.9	18
1900/01	5	<0.01	0.02	0.14	0.1	0.02	0.02	6	1.1	9	5.4	9
1901	1	<0.01	0.01	0.57	0.1	<0.01	0.04	5	2.4	2	4	14
1901	2	<0.01	<0.01	0.2	0.14	<0.01	0.03	5	1.9	8	3	14
1901	3	<0.01	<0.01	0.16	0.16	<0.01	0.03	5	1.5	3	2.4	13
1901	4	<0.01	0.01	0.14	0.18	0.01	0.02	5	1	3	3.2	15
1901	5	<0.01	0.02	0.14	0.13	0.01	0.02	5	0.9	8	4.6	10
1901/02	1	<0.01	0.01	0.49	0.12	<0.01	0.04	6	2.5	13	4.2	14
1901/02	2	<0.01	<0.01	0.19	0.17	<0.01	0.03	4	1.7	8	4.2	19

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1890 to 1903/04.

1901/02	3	<0.01	<0.01	0.12	0.16	<0.01	0.03	5	1.6	10	2.5	11
1901/02	4	<0.01	<0.01	0.11	0.2	<0.01	0.02	5	1.3	3	2.7	9
1901/02	5	<0.01	0.01	0.11	0.16	0.01	0.02	5	0.8	10	4	6.8
1902	1	<0.01	0.01	0.53	0.1	<0.01	0.05	7	2.6	32	4.2	6.2
1902	2	<0.01	<0.01	0.22	0.17	<0.01	0.03	5	1.2	3	3.6	5.6
1902	3	<0.01	<0.01	0.14	0.14	<0.01	0.03	5	1.6	9	2.3	13
1902	4	<0.01	<0.01	0.14	0.17	<0.01	0.03	5	1.5	3	2.6	5.1
1902	5	<0.01	0.01	0.14	0.17	0.01	0.02	7	1.4	13	4.9	8.5
1902/03	1	<0.01	0.01	0.44	0.08	<0.01	0.05	6	2.9	33	4.9	9.1
1902/03	2	<0.01	0.01	0.18	0.15	<0.01	0.03	5	1.8	12	5.7	9.6
1902/03	3	<0.01	<0.01	0.12	0.12	<0.01	0.03	4	1.2	7	3.9	13
1902/03	4	<0.01	<0.01	0.09	0.1	<0.01	0.03	4	1.2	13	2.8	7
1902/03	5	<0.01	0.01	0.09	0.1	0.01	0.02	4	1.8	9	2.7	13
1903	1	<0.01	0.03	0.51	0.03	<0.01	0.05	6	3	9	4.2	6.8
1903	2	<0.01	0.02	0.18	0.09	0.01	0.03	6	1.7	3	5.1	11
1903	3	<0.01	0.01	0.12	0.1	0.01	0.03	6	1.5	12	4.4	18
1903	4	<0.01	0.02	0.11	0.12	0.01	0.02	5	1.4	12	5	20
1903	5	<0.01	0.01	0.12	0.11	0.01	0.02	5	1.2	13	5.8	17
1903/1904	1	<0.01	0.02	0.48	0.04	0.01	0.04	6	2.7	20	3.7	13
1903/1904	2	<0.01	0.02	0.14	0.11	0.01	0.03	6	1.7	10	4.6	18
1903/1904	3	<0.01	0.01	0.11	0.15	0.02	0.03	6	1.2	4	4	10
1903/1904	4	<0.01	0.01	0.09	0.14	0.02	0.02	6	0.9	13	4.1	17
1903/1904	5	<0.01	0.01	0.08	0.11	0.01	0.02	5	0.9	9	3.8	6.8

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1978/79 to 1984/85.

Year	cm section	P (ICP) %db	K (ICP) %db	Ca (ICP) %db	Mg (ICP) %db	Na (ICP) %db	S (ICP) %db	B (ICP) mg/kg	Cu (ICP) mg/kg	Fe (ICP) mg/kg	Mn (ICP) mg/kg	Zn (ICP) mg/kg
1978/79	1	<0.01	0.06	0.46	0.03	0.01	0.06	6	3	28	4	35
1978/79	2	<0.01	0.04	0.18	0.08	0.01	0.04	5	2.1	47	4.4	39
1978/79	3	<0.01	0.06	0.15	0.15	0.01	0.04	4	1.7	24	4.7	29
1978/79	4	<0.01	0.1	0.11	0.23	0.02	0.03	3	1.2	11	3.6	17
1978/79	5	<0.01	0.12	0.1	0.28	0.03	0.02	3	2	36	4.2	32
1979	1	<0.01	0.06	0.57	0.04	<0.01	0.07	6	3.4	9	5	11
1979	2	<0.01	0.04	0.27	0.09	<0.01	0.04	4	2	9	5.5	21
1979	3	<0.01	0.07	0.21	0.12	0.01	0.05	4	2.3	22	5.3	23
1979	4	<0.01	0.1	0.21	0.15	0.02	0.03	4	1.4	28	3.9	21
1979	5	<0.01	0.1	0.18	0.2	0.02	0.02	3	2.8	78	4.3	72
1979/80	1	0.01	0.07	0.56	0.04	<0.01	0.08	6	3.3	17	4.7	18
1979/80	2	<0.01	0.04	0.22	0.08	0.01	0.05	4	1.9	20	4.4	28
1979/80	3	<0.01	0.11	0.17	0.12	0.02	0.04	5	2	6	3.6	16
1979/80	4	<0.01	0.19	0.12	0.22	0.02	0.03	4	2.2	8	3	18
1979/80	5	<0.01	0.15	0.1	0.27	0.03	0.02	3	1.7	20	3.2	27
1980	1	<0.01	0.06	0.55	0.04	<0.01	0.07	6	3.6	23	4.5	20
1980	2	<0.01	0.02	0.26	0.08	<0.01	0.05	4	1.9	10	4.1	16
1980	3	<0.01	0.05	0.19	0.1	0.01	0.05	4	2.5	14	3.4	29
1980	4	<0.01	0.13	0.18	0.14	0.02	0.03	4	1.7	13	3	22
1980	5	<0.01	0.14	0.16	0.22	0.03	0.02	4	1.3	7	3.6	18
1980/81	1	<0.01	0.06	0.62	0.08	<0.01	0.08	7	3.9	21	5.4	37
1980/81	2	<0.01	0.01	0.25	0.15	<0.01	0.05	4	1.6	9	4.7	20
1980/81	3	<0.01	0.03	0.18	0.12	0.01	0.05	3	1.9	10	3	17
1980/81	4	<0.01	0.08	0.14	0.18	0.02	0.03	4	2.1	34	2.8	41
1980/81	5	<0.01	0.1	0.12	0.24	0.02	0.02	3	1.6	16	4.9	24
1982	1	0.01	0.09	0.6	0.03	<0.01	0.09	7	3.8	22	5.4	27
1982	2	<0.01	0.04	0.26	0.08	0.01	0.04	4	1.8	13	4.2	22
1982	3	<0.01	0.06	0.21	0.09	0.01	0.04	4	1.7	10	3.6	21
1982	4	<0.01	0.1	0.16	0.13	0.02	0.03	3	1.5	20	2.8	71
1982	5	<0.01	0.12	0.14	0.2	0.02	0.02	3	1.1	18	2.5	45
1982/83	1	<0.01	0.06	0.51	0.05	<0.01	0.08	7	3.6	7	5.1	21
1982/83	2	<0.01	0.02	0.19	0.11	<0.01	0.04	4	1.7	4	4.4	19
1982/83	3	<0.01	0.05	0.13	0.12	0.01	0.04	4	2.2	44	3.6	34
1982/83	4	<0.01	0.09	0.1	0.17	0.01	0.02	3	1.5	22	2.8	31
1982/83	5	<0.01	0.1	0.09	0.23	0.02	0.02	3	1.2	21	3	23
1983	1	0.01	0.06	0.53	0.07	<0.01	0.07	6	3.7	14	5.7	26
1983	2	<0.01	0.01	0.28	0.15	<0.01	0.04	4	1.7	13	5	23

Gyngoorda stem (Stem 1) - Nutrient analyses results for all 5cm leaf base sections from 1978/79 to 1984/85.

1983	3	<0.01	0.02	0.2	0.14	<0.01	0.04	3	1.8	6	3.2	18
1983	4	<0.01	0.04	0.16	0.18	0.01	0.02	3	1.4	7	2.6	16
1983	5	<0.01	0.05	0.14	0.2	0.02	0.02	4	1.3	24	3.6	27
1983/84	1	0.01	0.06	0.46	0.07	<0.01	0.07	6	3.6	22	6	16
1983/84	2	<0.01	0.01	0.18	0.14	<0.01	0.04	4	1.9	9	5.3	26
1983/84	3	<0.01	0.02	0.14	0.16	<0.01	0.04	4	3.4	30	5	28
1983/84	4	<0.01	0.08	0.12	0.17	0.01	0.03	3	2.3	11	4.1	25
1983/84	5	<0.01	0.13	0.1	0.22	0.03	0.02	3	1.5	32	4.4	21
1984	1	<0.01	0.06	0.46	0.06	<0.01	0.07	6	3.6	11	5.6	14
1984	2	<0.01	0.02	0.19	0.14	<0.01	0.04	3	1.5	6	5.4	7.9
1984	3	<0.01	0.03	0.16	0.14	<0.01	0.05	3	2.3	10	4.9	12
1984	4	<0.01	0.06	0.12	0.15	0.01	0.04	3	2.1	4	3	6
1984	5	<0.01	0.12	0.12	0.19	0.04	0.03	4	2.3	30	6.3	25
1984/85	1	<0.01	0.07	0.44	0.07	<0.01	0.07	6	3.5	14	5.7	16
1984/85	2	<0.01	0.03	0.15	0.14	0.01	0.03	3	1.6	17	5	24
1984/85	3	<0.01	0.04	0.12	0.16	0.01	0.04	3	1.7	20	5.2	16
1984/85	4	<0.01	0.06	0.1	0.22	0.03	0.03	3	1.6	17	5.5	8.6
1984/85	5	<0.01	0.07	0.11	0.23	0.07	0.03	3	2.9	57	24	20

Nutrient analysis of all five leaf base sections - representative graphs (Stem 1).

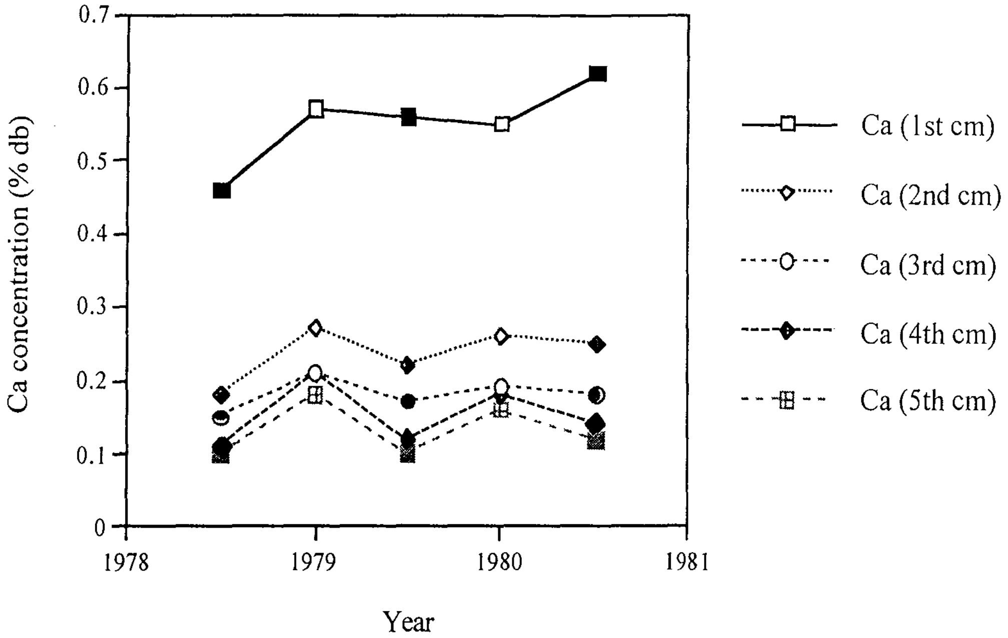

Figure 1. The concentration of Ca within all five sections of leaf bases from Stem 1 for the years 1978/79 to 1980/81.

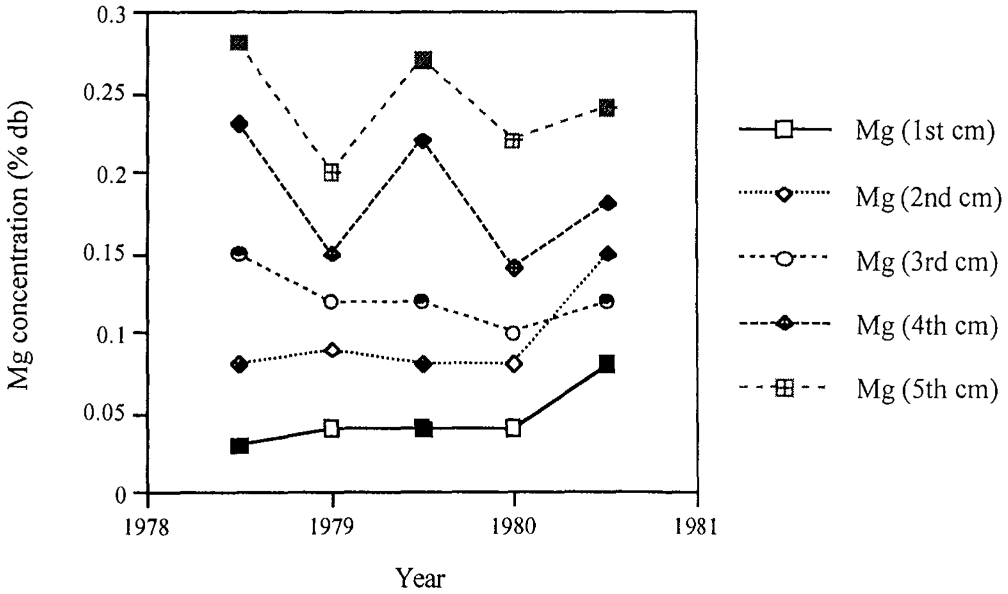

Figure 2. The concentration of Mg within all five sections of leaf bases from Stem 1 for the years 1978/79 to 1980/81.

Appendix 4

Soil Analyses Technique Descriptions

SUMMARY OF CSBP SOIL ANALYSIS METHODS

PHOSPHORUS AND POTASSIUM

REF. Rayment, GE and Higginson, FR (1992). Phosphorus. In 'Australian Laboratory Handbook of Soil and Chemical Methods ' (Inkata Press, Melbourne) pp 64-66.

Rayment, GE and Higginson, FR (1992). Extractable Potassium. In 'Australian Laboratory Handbook of Soil and Chemical Methods.' (Inkata Press, Melbourne) pp 203-204.

Available phosphorus and potassium are measured using the Colwell method:

Soils are tumbled with 0.5M sodium bicarbonate solution adjusted to pH 8.5 for 16 hours at 25^0C employing a soil:solution ratio of 1:100.

The acidified extract is treated with ammonium molybdate/antimony trichloride reagent and the concentration of phosphate is measured colorimetrically at 880nm.

The concentration of potassium is determined using a flame atomic absorption spectrophotometer at 766.5nm.

AMMONIUM AND NITRATE

The ammonium and nitrate nitrogen are measured simultaneously using a Lachat Flow Injection Analyser. Soils are tumbled with 1M potassium chloride for 1 hour at 25^0C employing a soil:solution ratio of 1:5.

The concentration of ammonium nitrogen is measured colorimetrically at 420nm using the indo-phenol blue reaction. REF: Searle, PL (1984) Analyst 109, 549-568.

The nitrate is reduced to nitrite through a copperized-cadmium column and the nitrite measured colorimetrically at 520nm.

pH WATER, CONDUCTIVITY AND pH CALCIUM CHLORIDE

REF: Rayment, GE and Higginson, FR (1992). Electrical Conductivity. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 15-16.

Rayment, GE and Higginson, FR (1992). Soil pH. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 17-20.

Soils are stirred in deionised water for 1 hour at 25^0C employing a soil:solution ratio of 1:5. The pHw of the extract is measured using a combination pH electrode and the electrical conductivity measured using a conductivity electrode calibrated against 0 01M KCl

After pHw and E C. have been measured, calcium chloride solution is added to produce a concentraion of 0 01M $CaCl_2$ and pHc in determined using a combination pH electrode.

ORGANIC CARBON

REF: Rayment, GE and Higginson, FR (1992). Organic Carbon. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 29-31.

Concentrated sulphuric acid is added to soil wetted with dichromate solution. The heat of dilution is used to induce oxidation of soil organic matter. The amount of chromic ions produced is proportional to the organic carbon oxidised and is measured colorimetrically at 600nm.

REACTIVE IRON

Soils are tumbled with Tamm's reagent (oxalic acid/ammonium oxalate) for 1 hour employing a soil:solution ratio of 1:33. The concentration of iron is determined using a flame atomic absorption spectrophotometer at 248.3nm.

EXTRACTABLE SULPHUR

REF: Blair, GJ, Chinoim, N, Lefroy, RDB, Anderson, GC and Crocker, GJ (1991) Aust J Soil Res 29, 619-626.

Soils are extracted at 40°C for 3 hours with 0.25M potassium chloride and the sulphate sulphur is measured by ICP.

SUMMARY OF SOIL NON-ROUTINE METHODS

TOTAL NITROGEN

Soil samples are combusted at 950^{0}C in oxygen using a Leco FP-428 Nitrogen Analyser.

TOTAL PHOSPHORUS

REF: Allen, DG and Jeffery, RC (1990) Report of Investigation NO: 37 "Methods for Analysis of Phosphorus in Western Australian Soils" page 7.

Soils are digested with sulphuric acid-potassium sulphate-copper sulphate and the phosphorus concentration measured colormetrically at 800nm.

DTPA TRACE ELEMENTS

REF: Rayment, GE and Higginson, FR (1992). Micronutrients. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 110-114.

Soils are extracted with diethylenetriaminepentaacetic acid (DTPA) for 2 hours and the concentration of copper, zinc, manganese and iron measured by AAS.

EDTA TRACE ELEMENTS

REF: Greenhill, N. State Chemistry Laboratory, 1985, Soils 020, 'Available copper and zinc in soil'.

Soils are extracted with EDTA (Ethylenediamine tetra-acetic acid di-sodium salt) solution at a ratio of 1:5 for 1 hour. The concentration of copper, zinc, manganese and iron are determined by ICP-AES.

EXCHANGEABLE CATIONS (Ca, Mg, Na, K)

REF: Rayment, GE and Higginson, FR (1992) Ion Exchange Properties. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 164-169.

The Gillman and Sumpter Method (p164) employs 0.1M $BaCl_2$/0.1M NH_4Cl extraction of exchangeable bases.

BORON

REF· Rayment, GE and Higginson, FR (1992) Micronutrients. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 115-120.

Soils are extracted with boiling 0.01M calcium chloride solution for 15 minutes and the boron concentration measured colormetrically with azomethine-H.

EXTRACTABLE ALUMINIUM

REF. Bromfield, SM (1987) Somple tests for the assessment of aluminium and manganese levels in acid Soils. Aust. J. Exp. Agric. 27, 399-404.

Soils are extracted with 0.01M calcium chloride solution and the extract analysed for aluminium by a colorimetric method using a catechol violet reagent.

PHOSPHORUS RETENTION INDEX

REF: Allen, DG and Jeffery, RC (1990) Methods for analysis of phosphorus in Western Australian Soil Report of Investigation NO. 37 Chemistry Centre WA, p 37.

Involves equilibration of soil with a solution initially containing 10ug/ml phosphorus for 16 hours. The solution is centrifuged and analysed for phosphorus using the method of Murphy and Riley. The amount of phosphorus absorbed by the soil is calculated from the difference between the initial concentration of phosphorus and the equilibrium concentration.

OLSEN P

REF: Rayment, GE and Higginson, FR (1992) Phosphorus. In "Australian Laboratory Handbook of Soil and Water Chemical Methods" (Inkata Press, Melbourne) pp 68-70.

The soil is extracted at a ratio of 1:20 with 0.5M $NaHCO_3$ (pH 8.5) for 30mins. The acidified extract is treated with ammonium molybdate/antimony trichloride reagent and the concentration of phosphorus is measured at 880nm.

Appendix 5

Chapter 4 - Chemical Analyses Raw Data

Gyngoorda stem (Stem 1) - Nutrient analyses results.

Year	cm section	P	K	Ca	Mg	Na	S	B	Cu	Fe	Mn	Zn
		(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
		%db	%db	%db	%db	%db	%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1890	1	<0.01	0.02	0.52	0.06	<0.01	0.04	4	3.2	20	4.6	26
1890	5	<0.01	0.02	0.16	0.08	0.02	0.02	3	1.3	24	6.6	7.3
1890/91	1	<0.01	0.02	0.5	0.05	<0.01	0.04	4	3.6	12	4	15
1890/91	5	<0.01	0.02	0.12	0.12	0.01	0.02	4	1.2	28	5.8	12
1891	1	<0.01	0.02	0.53	0.07	<0.01	0.04	5	3.5	61	4.6	28
1891	5	<0.01	0.01	0.12	0.13	0.01	0.02	4	1.4	120	5.9	20
1891/92	1	<0.01	0.01	0.52	0.09	<0.01	0.03	5	2.7	18	4.3	19
1891/92	5	<0.01	0.01	0.12	0.1	<0.01	0.02	4	0.8	27	5.2	12
1892	1	<0.01	0.01	0.57	0.13	<0.01	0.03	4	2.3	25	3.6	13
1892	5	<0.01	0.01	0.13	0.08	0.01	0.01	3	4.1	1200	15	54
1892/93	1	<0.01	0.01	0.44	0.12	<0.01	0.04	5	2.4	38	6.3	13
1892/93	5	<0.01	0.01	0.12	0.11	<0.01	0.02	3	1.5	14	4.4	1.8
1893	1	<0.01	0.02	0.48	0.08	<0.01	0.04	6	3	12	5.4	12
1893	5	<0.01	0.02	0.14	0.11	<0.01	0.02	4	2.4	52	8.4	35
1893/94	1	<0.01	0.02	0.48	0.06	<0.01	0.03	5	2.9	33	4.7	20
1893/94	5	<0.01	0.02	0.16	0.09	0.01	0.02	4	3.4	340	9.6	82
1894	1	<0.01	0.02	0.57	0.09	<0.01	0.04	5	2.9	20	4.4	16
1894	5	<0.01	0.02	0.16	0.12	0.01	0.02	5	2.3	300	9.6	73
1894/95	1	<0.01	0.02	0.62	0.1	<0.01	0.04	5	2.7	15	4.6	15
1894/95	5	<0.01	0.02	0.15	0.1	0.01	0.02	4	1	55	6	23
1895	1	<0.01	0.01	0.63	0.12	<0.01	0.04	4	2.6	24	4.3	11
1895	5	<0.01	0.01	0.19	0.1	0.02	0.02	3	1.4	38	6	7.9
1895/96	1	<0.01	0.01	0.47	0.13	<0.01	0.04	4	2.4	15	5.4	11
1895/96	5	<0.01	0.01	0.12	0.12	<0.01	0.02	4	1.5	10	4.3	4.2
1896	1	<0.01	0.02	0.55	0.06	0.01	0.05	6	3	11	4.9	18
1896	5	<0.01	0.02	0.17	0.12	0.01	0.03	4	1.2	16	7.8	18
1896/97	1	<0.01	0.02	0.56	0.06	0.01	0.04	4	2.7	18	4.3	12
1896/97	5	<0.01	0.02	0.13	0.1	0.02	0.02	5	0.9	22	7	12
1897	1	<0.01	0.01	0.54	0.1	<0.01	0.04	4	2.5	24	4.1	12
1897	5	<0.01	0.02	0.19	0.1	0.02	0.02	5	0.8	27	6.6	16
1897/98	1	<0.01	0.01	0.48	0.1	<0.01	0.04	4	2.2	18	4.1	14
1897/98	5	<0.01	0.02	0.16	0.12	0.02	0.02	5	0.7	25	6.4	11
1898	1	<0.01	0.01	0.54	0.09	<0.01	0.04	4	2	52	3.8	12
1898	5	<0.01	0.02	0.16	0.12	0.02	0.02	3	1.2	31	5.7	14
1898/99	1	<0.01	0.01	0.56	0.11	<0.01	0.04	4	2.6	14	3.9	9.9
1898/99	5	<0.01	0.01	0.14	0.08	0.02	0.02	2	1.4	20	4.4	11
1899	1	<0.01	0.01	0.45	0.11	<0.01	0.04	4	2.2	11	3.8	6.5
1899	5	<0.01	0.02	0.16	0.08	0.01	0.02	4	1.7	16	5	11
1899/00	1	<0.01	0.01	0.44	0.1	<0.01	0.04	5	2.2	11	5.5	7.1

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1899/00	5	<0.01	0.01	0.13	0.09	0.01	0.03	5	1.4	35	4.5	6.3
1900	1	<0.01	0.02	0.6	0.07	<0.01	0.05	7	2.9	20	5.1	22
1900	5	<0.01	0.01	0.15	0.11	0.02	0.02	6	1.6	7	5.2	17
1900/01	1	<0.01	0.02	0.56	0.06	0.01	0.04	6	2.8	14	4.2	19
1900/01	5	<0.01	0.02	0.14	0.1	0.02	0.02	6	1.1	9	5.4	9
1901	1	<0.01	0.01	0.57	0.1	<0.01	0.04	5	2.4	2	4	14
1901	5	<0.01	0.02	0.14	0.13	0.01	0.02	5	0.9	8	4.6	10
1901/02	1	<0.01	0.01	0.49	0.12	<0.01	0.04	6	2.5	13	4.2	14
1901/02	5	<0.01	0.01	0.11	0.16	0.01	0.02	5	0.8	10	4	6.8
1902	1	<0.01	0.01	0.53	0.1	<0.01	0.05	7	2.6	32	4.2	6.2
1902	5	<0.01	0.01	0.14	0.17	0.01	0.02	7	1.4	13	4.9	8.5
1902/03	1	<0.01	0.01	0.44	0.08	<0.01	0.05	6	2.9	33	4.9	9.1
1902/03	5	<0.01	0.01	0.09	0.1	0.01	0.02	4	1.8	9	2.7	13
1903	1	<0.01	0.03	0.51	0.03	<0.01	0.05	6	3	9	4.2	6.8
1903	5	<0.01	0.01	0.12	0.11	0.01	0.02	5	1.2	13	5.8	17
1903/1904	1	<0.01	0.02	0.48	0.04	0.01	0.04	6	2.7	20	3.7	13
1903/1904	5	<0.01	0.01	0.08	0.11	0.01	0.02	5	0.9	9	3.8	6.8
1904	1	<0.01	0.02	0.65	0.05	<0.01	0.05	6	10.5	10	4.1	11.3
1904	5	<0.01	0.01	0.13	0.12	0.02	0.02	6	1.5	5	4.8	6.1
1904/05	1	<0.01	0.02	0.64	0.07	<0.01	0.04	5	6.4	7	4	10.8
1904/05	5	<0.01	0.01	0.12	0.14	0.01	0.02	5	3.2	5	4.4	7.1
1905	1	<0.01	0.04	0.68	0.08	<0.01	0.05	6	3.2	6	4.2	9.5
1905	5	<0.01	0.02	0.18	0.14	0.01	0.02	5	1.6	9	4.2	5.6
1905/06	1	<0.01	0.03	0.52	0.08	<0.01	0.05	6	2.9	9	4.5	5.1
1905/06	5	<0.01	0.01	0.13	0.13	<0.01	0.02	3	2.2	8	3.9	3.2
1906	1	<0.01	0.03	0.59	0.06	0.01	0.05	6	3.3	4	4.9	11.1
1906	5	<0.01	0.02	0.15	0.12	0.02	0.02	5	1.4	9	5.3	16.1
1906/07	1	<0.01	0.03	0.57	0.06	0.01	0.05	6	3	9	4.3	18
1906/07	5	<0.01	0.01	0.11	0.13	0.02	0.02	4	0.9	15	4	12
1907	1	<0.01	0.02	0.58	0.07	<0.01	0.05	5	2.6	5	4.3	8.3
1907	5	<0.01	0.02	0.14	0.09	0.02	0.02	4	1.3	27	4.3	17
1907/08	1	<0.01	0.02	0.71	0.07	<0.01	0.04	5	2.6	11	5.4	3.4
1907/08	5	<0.01	0.01	0.14	0.11	<0.01	0.03	3	1.8	7	2.6	3.2
1908	1	<0.01	0.02	0.58	0.07	0.01	0.05	7	3.9	12	4.1	13.8
1908	5	<0.01	0.02	0.16	0.13	0.02	0.02	5	0.9	8	4.9	9.8
1908/09	1	<0.01	0.03	0.58	0.05	0.01	0.05	6	2.7	7	4.1	10.2
1908/09	5	<0.01	0.02	0.11	0.11	0.02	0.02	5	1.8	13	4	9.7
1909	1	<0.01	0.02	0.47	0.06	<0.01	0.04	5	2.7	13	4.1	9.5
1909	5	<0.01	0.02	0.14	0.14	0.02	0.03	6	1.1	16	5.7	9.8
1909/10	1	<0.01	0.02	0.41	0.09	<0.01	0.04	5	2	12	6.2	10.7
1909/10	5	<0.01	0.02	0.14	0.11	0.01	0.03	3	1.5	13	4.6	15.8
1910	1	<0.01	0.06	0.5	0.08	0.04	0.04	7	8.1	17	5	17.5

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1910	5	<0.01	0.06	0.14	0.15	0.05	0.03	7	1.1	18	6.1	16.8
1910/11	1	<0.01	0.03	0.56	0.06	0.02	0.05	7	3	4	4.2	14.5
1910/11	5	<0.01	0.03	0.12	0.15	0.04	0.03	7	0.8	13	5.4	13.1
1911	1	<0.01	0.03	0.63	0.08	0.02	0.05	7	2.9	3	4	12.6
1911	5	<0.01	0.02	0.17	0.18	0.03	0.03	7	1	8	5.3	11
1911/12	1	<0.01	0.02	0.53	0.08	0.01	0.05	5	2.6	4	4.5	14.1
1911/12	5	<0.01	0.02	0.15	0.2	0.02	0.03	7	1	6	5.7	10.6
1912	1	<0.01	0.01	0.58	0.09	0.01	0.05	5	2.6	3	3.1	7.7
1912	5	<0.01	0.01	0.16	0.2	0.02	0.03	6	1	9	4.6	10.2
1912/13	1	<0.01	0.01	0.53	0.09	<0.01	0.05	5	2.6	4	3.5	7.7
1912/13	5	<0.01	0.02	0.14	0.17	0.02	0.03	7	0.7	12	5.4	8.8
1913	1	<0.01	0.01	0.42	0.1	<0.01	0.05	5	2.5	19	3.7	5.3
1913	5	<0.01	0.01	0.12	0.15	0.02	0.03	7	1	7	5	5.3
1913/14	1	<0.01	0.01	0.45	0.11	<0.01	0.05	5	2.4	3	3.4	9.5
1913/14	5	<0.01	0.02	0.12	0.14	0.03	0.02	6	1.2	36	5.1	12.4
1914	1	<0.01	0.01	0.45	0.1	<0.01	0.05	5	2.6	6	4	6
1914	5	<0.01	0.01	0.13	0.16	0.02	0.03	7	1.4	7	4.7	7.4
1914/15	1	<0.01	0.01	0.4	0.1	<0.01	0.04	5	2.8	23	4.1	10.2
1914/15	5	<0.01	0.02	0.12	0.14	0.02	0.02	6	1.4	61	6.4	13.2
1915	1	<0.01	0.01	0.44	0.1	<0.01	0.04	5	2.7	3	4.8	6.5
1915	5	<0.01	0.01	0.12	0.15	0.01	0.03	6	1.6	8	4.6	20.7
1915/16	1	<0.01	0.01	0.45	0.1	<0.01	0.04	6	3.1	150	6.9	15.5
1915/16	5	<0.01	<0.01	0.09	0.11	<0.01	0.03	3	1.4	11	3.3	9.7
1916	1	<0.01	0.02	0.59	0.05	<0.01	0.05	5	3.8	10	3.9	14
1916	5	<0.01	0.02	0.11	0.14	0.01	0.02	5	0.9	11	3.9	12.9
1916/17	1	<0.01	0.02	0.54	0.07	0.01	0.04	6	2.7	13	4.1	14.9
1916/17	5	<0.01	0.02	0.09	0.15	0.02	0.02	5	1.5	25	3.2	10.9
1917	1	<0.01	0.02	0.55	0.07	0.01	0.05	5	3.2	8	4	11
1917	5	<0.01	0.02	0.18	0.18	0.03	0.03	7	1	13	5.4	6.9
1917/18	1	<0.01	0.01	0.44	0.08	<0.01	0.04	6	2.4	7	5	5.2
1917/18	5	<0.01	<0.01	0.13	0.12	<0.01	0.03	3	1.6	8	3.8	3.4
1918	1	<0.01	0.03	0.59	0.05	0.01	0.05	7	3.2	21	7	27.8
1918	5	<0.01	0.04	0.17	0.13	0.02	0.03	6	1.2	15	7.6	11.2
1918/19	1	<0.01	0.03	0.52	0.08	0.03	0.04	8	2.7	8	4.6	13.2
1918/19	5	<0.01	0.03	0.13	0.12	0.04	0.03	6	1.2	18	5.2	9.9
1919	1	<0.01	0.02	0.54	0.07	0.01	0.04	7	3	8	4.3	8.1
1919	5	<0.01	0.03	0.15	0.16	0.04	0.04	8	1.1	27	6.9	9.8
1919/20	1	<0.01	0.01	0.47	0.08	<0.01	0.04	5	2.8	8	5.5	6.5
1919/20	5	<0.01	0.01	0.13	0.1	0.01	0.03	3	1.7	12	3.2	3.5
1920	1	<0.01	0.02	0.43	0.08	0.01	0.04	6	2.7	21	4.9	17.8
1920	5	<0.01	0.02	0.13	0.14	0.02	0.02	6	0.9	10	4.8	12.6
1920/21	1	<0.01	0.03	0.47	0.07	0.02	0.04	7	4.1	<10	4.4	15.9

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1920/21	5	<0.01	0.02	0.11	0.16	0.03	0.03	6	1.1	18	3.7	11
1921	1	<0.01	0.02	0.48	0.07	0.01	0.04	5	2.7	6	3.6	10
1921	5	<0.01	0.02	0.13	0.13	0.02	0.02	6	1	<10	3.6	6.7
1921/22	1	<0.01	0.02	0.51	0.08	<0.01	0.04	6	2.6	<10	4.4	9.9
1921/22	5	<0.01	0.02	0.11	0.15	0.02	0.02	6	0.7	11	3.6	7.2
1922	1	<0.01	0.02	0.54	0.1	<0.01	0.04	6	2.7	<10	4.5	9
1922	5	<0.01	0.01	0.11	0.14	0.01	0.02	3	0.7	<10	2.3	5.5
1922/23	1	<0.01	0.03	0.48	0.1	<0.01	0.05	6	2.6	<10	4.8	5.9
1922/23	5	<0.01	0.02	0.14	0.15	0.01	0.02	4	0.7	15	2.9	6
1923	1	<0.01	0.02	0.42	0.11	<0.01	0.04	6	2.5	<10	4.5	9
1923	5	<0.01	0.02	0.1	0.13	0.02	0.02	5	1.1	13	3.4	4
1923/24	1	<0.01	0.01	0.4	0.12	<0.01	0.04	5	2.7	<10	5	4.1
1923/24	5	<0.01	0.01	0.11	0.14	0.01	0.03	3	1.4	<10	2.2	3.5
1924	1	<0.01	0.03	0.42	0.05	<0.01	0.04	5	3.1	<10	4.6	10.6
1924	5	<0.01	0.1	0.1	0.16	0.02	0.02	5	1.7	<10	5.1	12
1924/25	1	<0.01	0.03	0.52	0.04	<0.01	0.04	5	3.1	<10	4.1	12.2
1924/25	5	<0.01	0.05	0.12	0.17	0.02	0.02	5	1.3	<10	4.4	10.8
1925	1	<0.01	0.04	0.58	0.06	0.01	0.05	5	2.7	<10	4.1	11.3
1925	5	<0.01	0.04	0.12	0.18	0.03	0.03	7	1.7	14	4	9.3
1925/26	1	<0.01	0.04	0.48	0.04	<0.01	0.04	6	2.8	<10	3.8	14.3
1925/26	5	<0.01	0.02	0.08	0.21	0.01	0.02	3	0.8	<10	2.4	11.6
1926	1	<0.01	0.03	0.62	0.07	<0.01	0.04	6	3	<10	4.4	12.8
1926	5	<0.01	0.02	0.11	0.2	0.01	0.02	4	1.1	<10	2.6	8.9
1926/27	1	<0.01	0.02	0.55	0.1	<0.01	0.04	6	3	<10	5	11.6
1926/27	5	<0.01	0.03	0.12	0.23	0.01	0.02	4	1	<10	2.5	8.3
1927	1	<0.01	0.02	0.52	0.11	<0.01	0.04	6	2.8	<10	5	7.1
1927	5	<0.01	0.02	0.13	0.11	0.01	0.02	4	1.7	<10	2.4	6
1927/28	1	<0.01	0.01	0.53	0.12	<0.01	0.04	5	2.6	31	4.8	5
1927/28	5	<0.01	0.01	0.13	0.14	0.01	0.02	3	1.7	<10	2	3.7
1928	1	<0.01	0.03	0.36	0.05	<0.01	0.04	5	3.3	23	5.2	9.1
1928	5	<0.01	0.12	0.1	0.18	0.02	0.02	5	2.3	10	4.6	16.5
1928/29	1	<0.01	0.03	0.44	0.04	<0.01	0.04	5	3.5	21	4.2	15.3
1928/29	5	<0.01	0.04	0.09	0.21	0.02	0.02	5	1.4	15	3.2	15.6
1929	1	<0.01	0.01	0.55	0.1	<0.01	0.03	5	2.6	<10	4.9	9
1929	5	<0.01	0.02	0.12	0.2	0.02	0.02	5	1.6	42	3.6	13
1929/30	1	<0.01	0.02	0.6	0.11	<0.01	0.04	6	3	<10	5.2	9.4
1929/30	5	<0.01	0.03	0.11	0.18	0.02	0.02	5	1.3	17	3.6	10
1930	1	<0.01	0.01	0.48	0.13	<0.01	0.03	5	2.6	8	4.7	7.8
1930	5	<0.01	0.03	0.13	0.17	0.02	0.02	4	1.8	14	3.2	7
1930/31	1	<0.01	0.01	0.4	0.12	<0.01	0.04	5	3.9	27	6	18.7
1930/31	5	<0.01	0.02	0.1	0.14	<0.01	0.03	3	2.4	19	3.2	23.1
1931	1	<0.01	0.04	0.53	0.04	<0.01	0.04	5	3.2	5	4.3	21.5

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1931	5	<0.01	0.04	0.11	0.18	0.02	0.03	5	1.3	10	3.4	17.8
1931/32	1	<0.01	0.04	0.46	0.04	0.01	0.04	5	4.3	28	4.2	46.4
1931/32	5	0.01	0.03	0.07	0.19	0.01	0.02	4	1.7	138	5.4	47.4
1932	1	<0.01	0.01	0.56	0.12	<0.01	0.04	5	4.2	26	4.9	35.4
1932	5	<0.01	0.02	0.13	0.18	0.02	0.02	5	1.4	39	4	19.1
1932/33	1	<0.01	0.01	0.46	0.14	<0.01	0.04	5	3.3	19	4.8	23.4
1932/33	5	<0.01	0.02	0.1	0.18	0.01	0.02	4	1.3	29	3.1	14.3
1933	1	<0.01	<0.01	0.51	0.16	<0.01	0.04	5	2.9	22	4.8	39.2
1933	5	<0.01	0.02	0.13	0.16	0.01	0.02	4	1.4	33	3.5	24.8
1933/34	1	<0.01	0.01	0.51	0.12	<0.01	0.04	5	2.9	25	4.8	35.2
1933/34	5	0.01	0.02	0.1	0.19	0.01	0.02	4	1.4	75	4	30.4
1934	1	<0.01	0.01	0.42	0.13	<0.01	0.04	5	4.2	15	5.2	20.4
1934	5	<0.01	0.03	0.12	0.18	0.02	0.02	5	1.9	25	4.2	14.6
1934/35	1	<0.01	0.02	0.48	0.1	<0.01	0.04	5	4.4	17	4.9	22.1
1934/35	5	0.01	0.03	0.09	0.17	0.02	0.03	3	2.7	30	4	20.7
1935	1	<0.01	0.01	0.44	0.11	<0.01	0.05	4	2.6	9	4.5	35.6
1935	5	<0.01	0.05	0.13	0.16	0.02	0.02	4	1.5	14	3.6	12.5
1935/36	1	<0.01	0.02	0.46	0.11	<0.01	0.04	5	3	14	6	17.1
1935/36	5	<0.01	0.04	0.11	0.15	0.01	0.03	3	1.7	18	4.6	9.7
1936	1	<0.01	0.06	0.65	0.05	0.01	0.05	6	3.3	6	4.2	29.6
1936	5	<0.01	0.08	0.13	0.2	0.04	0.03	5	0.8	17	4.2	26.2
1936/37	1	<0.01	0.06	0.57	0.04	0.01	0.06	6	3.4	14	4.5	26.6
1936/37	5	<0.01	0.06	0.11	0.22	0.03	0.02	4	1	35	3.9	21
1937	1	<0.01	0.04	0.55	0.08	0.01	0.05	5	2.4	10	6.9	22.1
1937	5	<0.01	0.06	0.13	0.12	0.04	0.02	4	0.7	15	2.9	15.2
1937/38	1	<0.01	0.04	0.6	0.08	0.01	0.05	5	2.6	9	5.6	17.2
1937/38	5	<0.01	0.05	0.12	0.19	0.04	0.02	5	0.8	27	3.5	12.4
1938	1	<0.01	0.03	0.48	0.09	<0.01	0.04	5	4.8	5	4.7	21
1938	5	<0.01	0.04	0.13	0.2	0.04	0.03	5	1	14	3.8	30.7
1938/39	1	<0.01	0.04	0.46	0.09	<0.01	0.05	5	2.8	8	5.2	15.9
1938/39	5	0.01	0.04	0.11	0.19	0.02	0.03	4	1.5	34	5.3	16.7
1939	1	<0.01	0.01	0.43	0.09	<0.01	0.04	4	2.7	3	4.5	10.3
1939	5	<0.01	0.04	0.12	0.23	0.03	0.03	5	1.3	18	5.4	33.3
1939/40	1	<0.01	0.03	0.45	0.08	<0.01	0.05	5	2.9	9	4.1	22.7
1939/40	5	<0.01	0.03	0.1	0.26	0.02	0.02	4	0.9	33	3.6	20.7
1940	1	<0.01	0.02	0.4	0.08	<0.01	0.04	4	2.9	6	4.6	21.5
1940	5	<0.01	0.04	0.11	0.21	0.03	0.03	6	1.1	20	5	33.6
1940/41	1	<0.01	0.07	0.4	0.06	<0.01	0.05	5	2.6	15	4.7	10.2
1940/41	5	<0.01	0.03	0.06	0.21	0.02	0.02	5	1.1	52	4.4	15.6
1941	1	<0.01	0.03	0.39	0.08	<0.01	0.04	5	2.6	8	4.5	10.9
1941	5	<0.01	0.03	0.12	0.22	0.02	0.03	5	1.6	27	4.6	19.3
1941/42	1	<0.01	0.03	0.48	0.09	<0.01	0.05	5	2.6	11	4.7	12.8

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1941/42	5	<0.01	0.03	0.09	0.25	0.02	0.03	4	1.2	27	4.6	14.1
1942	1	<0.01	0.03	0.44	0.08	<0.01	0.05	4	3	8	5	22.2
1942	5	<0.01	0.03	0.13	0.22	0.02	0.03	6	1.7	20	5.6	12.7
1942/43	1	<0.01	0.03	0.46	0.09	<0.01	0.05	5	4.6	7	4.8	11.8
1942/43	5	<0.01	0.02	0.1	0.22	0.02	0.02	4	1.2	17	3.1	17.6
1943	1	<0.01	0.05	0.39	0.08	<0.01	0.05	5	3.7	22	5.1	15
1943	5	<0.01	0.03	0.12	0.13	0.02	0.02	3	1.5	28	3.3	20.7
1943/44	1	<0.01	0.03	0.32	0.08	<0.01	0.04	4	2.5	8	5.8	7.1
1943/44	5	<0.01	0.03	0.1	0.13	0.01	0.03	2	1.5	15	3.8	7.7
1944	1	<0.01	0.04	0.52	0.03	<0.01	0.05	5	3.6	20	4.1	39.5
1944	5	<0.01	0.04	0.11	0.16	0.02	0.03	4	1.5	35	5	30.8
1944/45	1	<0.01	0.05	0.49	0.04	<0.01	0.05	4	4.8	19	4.7	29.5
1944/45	5	<0.01	0.04	0.07	0.22	0.02	0.02	3	1.3	22	3.1	21.9
1945	1	<0.01	0.06	0.5	0.05	0.01	0.05	5	3.1	8	4.4	27.7
1945	5	<0.01	0.04	0.12	0.2	0.02	0.03	4	1.5	50	6.2	27
1945/46	1	<0.01	0.05	0.53	0.08	<0.01	0.06	5	2.9	9	4.6	16
1945/46	5	<0.01	0.02	0.1	0.22	0.02	0.02	3	1.1	25	3.2	19.4
1946	1	<0.01	0.04	0.56	0.09	<0.01	0.05	5	2.9	4	4.2	11.7
1946	5	0.01	0.03	0.16	0.18	0.02	0.03	4	2.4	288	7.7	27.4
1946/47	1	<0.01	0.03	0.43	0.1	<0.01	0.05	5	2.7	6	4.5	7
1946/47	5	<0.01	0.02	0.12	0.18	0.01	0.02	3	1.4	7	3.2	10.8
1947	1	<0.01	0.04	0.46	0.09	<0.01	0.05	6	4	233	6.5	23.2
1947	5	<0.01	0.03	0.14	0.23	0.02	0.02	4	1.5	14	5	11.4
1947/48	1	<0.01	0.04	0.52	0.05	<0.01	0.06	6	3.5	40	4	31
1947/48	5	<0.01	0.02	0.11	0.27	0.01	0.03	3	1.5	15	3	26.5
1948	1	<0.01	0.02	0.51	0.05	<0.01	0.05	5	3.3	26	4.2	22.6
1948	5	<0.01	0.02	0.13	0.16	0.01	0.03	4	1.7	13	3.7	17.1
1948/49	1	<0.01	0.02	0.29	0.05	<0.01	0.04	5	3	8	5.9	4.5
1948/49	5	<0.01	0.03	0.1	0.1	0.01	0.04	4	2.7	10	5.4	46.5
1949	1	<0.01	0.02	0.38	0.06	<0.01	0.04	5	2.9	2	4.4	11.9
1949	5	<0.01	0.04	0.14	0.17	0.02	0.03	5	1.4	6	4	13.4
1949/50	1	<0.01	0.03	0.51	0.05	<0.01	0.05	5	2.9	6	4.2	16.9
1949/50	5	<0.01	0.03	0.08	0.19	0.01	0.02	3	1.1	16	3	13.6
1950	1	<0.01	0.01	0.51	0.09	<0.01	0.04	4	3	8	4.7	30.9
1950	5	<0.01	0.04	0.13	0.12	0.02	0.02	3	1.1	14	3.3	12.2
1950/51	1	<0.01	0.02	0.48	0.12	<0.01	0.05	6	2.7	9	7.2	11.5
1950/51	5	<0.01	0.02	0.11	0.11	0.01	0.03	2	1.5	6	3.2	6
1951	1	<0.01	0.02	0.82	0.07	<0.01	0.06	6	3.8	8	4.8	24.5
1951	5	<0.01	0.04	0.2	0.18	0.02	0.03	4	2.1	19	3.5	17.8
1951/52	1	<0.01	0.02	0.46	0.11	<0.01	0.04	4	2.8	7	5.7	6.6
1951/52	5	<0.01	0.03	0.15	0.14	0.02	0.02	4	1.6	16	4.8	11.6
1952	1	<0.01	0.01	0.45	0.1	<0.01	0.03	4	2.3	3	3.8	23.2

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1952	5	<0.01	0.03	0.15	0.18	0.02	0.02	4	1.2	7	4.1	21.8
1952/53	1	<0.01	0.01	0.46	0.1	<0.01	0.03	4	2.1	9	3.6	33.9
1952/53	5	<0.01	0.01	0.13	0.18	0.02	0.02	3	0.9	5	2.2	20.9
1953	1	<0.01	<0.01	0.34	0.1	<0.01	0.03	4	2.4	22	3.8	15.9
1953	5	<0.01	0.01	0.14	0.15	0.02	0.02	3	1.6	36	3.3	19.3
1953/54	1	<0.01	<0.01	0.4	0.1	<0.01	0.03	4	2.4	8	3.8	26.9
1953/54	5	<0.01	0.02	0.1	0.21	0.02	0.02	4	1.3	14	3	18.9
1954	1	<0.01	<0.01	0.47	0.12	<0.01	0.03	4	2.5	13	3.9	15.8
1954	5	<0.01	0.01	0.13	0.19	0.01	0.02	4	1.6	31	2.7	13.9
1954/55	1	<0.01	<0.01	0.46	0.09	<0.01	0.04	4	2.6	8	4	17
1954/55	5	<0.01	0.02	0.11	0.23	0.01	0.02	4	1	28	2.9	15.6
1955	1	<0.01	<0.01	0.39	0.12	<0.01	0.03	4	2.6	8	3.9	16
1955	5	<0.01	0.02	0.11	0.18	0.02	0.02	4	1.7	18	2.8	12.9
1955/56	1	<0.01	0.01	0.45	0.12	<0.01	0.04	4	2.6	16	4.7	17.4
1955/56	5	<0.01	0.02	0.1	0.22	0.02	0.02	4	1.6	16	2.6	11.1
1956	1	<0.01	0.02	0.35	0.11	<0.01	0.04	4	3.1	19	4.9	17.4
1956	5	<0.01	0.03	0.11	0.16	0.02	0.02	4	2.1	18	3.4	12.7
1956/57	1	<0.01	0.01	0.41	0.09	<0.01	0.04	4	2.8	12	4.3	16.9
1956/57	5	<0.01	0.02	0.09	0.17	0.02	0.02	4	1	14	2.5	13.9
1957	1	<0.01	0.02	0.4	0.07	<0.01	0.04	4	2.7	6	3.7	18.1
1957	5	<0.01	0.02	0.1	0.17	0.02	0.02	3	2.2	22	3	15.8
1957/58	1	<0.01	0.01	0.42	0.1	<0.01	0.04	5	2.8	20	4.3	15.2
1957/58	5	<0.01	0.03	0.1	0.2	0.01	0.02	3	1.8	10	2.4	14.6
1958	1	<0.01	0.01	0.43	0.1	<0.01	0.04	4	2.8	11	4.2	12.8
1958	5	<0.01	0.02	0.11	0.16	0.01	0.02	4	1.6	10	2.6	11.1
1958/59	1	<0.01	0.01	0.43	0.11	<0.01	0.04	5	2.6	8	4.6	17
1958/59	5	<0.01	0.03	0.1	0.21	0.01	0.02	3	2	18	2.6	14.8
1959	1	<0.01	0.01	0.47	0.1	<0.01	0.03	4	3.5	8	4	17.1
1959	5	<0.01	0.03	0.12	0.17	0.01	0.02	3	1.2	7	2.6	10.6
1959/60	1	<0.01	0.01	0.47	0.14	<0.01	0.04	4	2.3	6	5.7	7.8
1959/60	5	<0.01	0.01	0.09	0.2	<0.01	0.03	2	1.3	11	2.2	7.2
1960	1	<0.01	0.03	0.34	0.07	<0.01	0.04	4	2.5	10	6.4	15.9
1960	5	<0.01	0.11	0.12	0.18	0.01	0.03	4	1.7	12	5.9	20.1
1960/61	1	<0.01	0.04	0.2	0.06	0.01	0.03	5	1.8	33	4.7	27.1
1960/61	5	<0.01	0.06	0.12	0.23	0.01	0.02	4	1.1	12	3.8	23.4
1961	1	<0.01	0.06	0.5	0.06	<0.01	0.05	5	3	8	5.5	14
1961	5	<0.01	0.06	0.11	0.18	0.02	0.02	4	2.4	6	3.7	13.1
1961/62	1	<0.01	0.06	0.48	0.07	<0.01	0.06	6	2.8	10	5.9	19.7
1961/62	5	<0.01	0.04	0.1	0.19	0.01	0.03	3	1.3	58	3.8	15.5
1962	1	0.01	0.09	0.52	0.08	<0.01	0.07	7	3.2	60	6	42.2
1962	5	<0.01	0.03	0.14	0.19	0.02	0.02	4	1.2	110	5.6	21.4
1962/63	1	<0.01	0.03	0.51	0.1	<0.01	0.04	5	2.6	6	5.7	17

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1962/63	5	<0.01	0.03	0.13	0.22	0.02	0.03	4	1.4	10	4.6	15.6
1963	1	<0.01	0.03	0.42	0.08	<0.01	0.04	4	4.6	6	4.9	12.7
1963	5	<0.01	0.04	0.13	0.17	0.02	0.03	4	1.8	18	4.7	15.8
1963/64	1	<0.01	0.05	0.5	0.07	<0.01	0.05	5	3	12	5.6	15.1
1963/64	5	<0.01	0.03	0.1	0.2	0.02	0.03	4	1.5	11	3.9	16.8
1964	1	<0.01	0.05	0.45	0.08	<0.01	0.05	5	3.2	10	5.9	23.9
1964	5	<0.01	0.03	0.13	0.12	0.02	0.03	4	1.1	16	4	19.2
1964/65	1	<0.01	0.06	0.52	0.07	<0.01	0.05	5	2.8	7	5.1	14.2
1964/65	5	<0.01	0.03	0.09	0.2	0.02	0.02	3	1.3	23	3.2	14.5
1965	1	<0.01	0.06	0.5	0.09	<0.01	0.06	6	2.7	12	5.5	15.5
1965	5	<0.01	0.05	0.14	0.19	0.02	0.02	4	1.1	11	3.1	12.8
1965/66	1	0.01	0.06	0.49	0.07	<0.01	0.05	5	3.4	8	5.7	13.4
1965/66	5	<0.01	0.08	0.09	0.26	0.02	0.02	3	1.2	12	3	13.9
1966	1	0.01	0.07	0.5	0.07	<0.01	0.06	6	4.3	29	5.7	15.3
1966	5	<0.01	0.06	0.12	0.22	0.02	0.02	3	1.4	18	3.8	16.4
1966/67	1	<0.01	0.05	0.52	0.08	<0.01	0.06	5	3.9	16	5.8	16.6
1966/67	5	<0.01	0.31	0.09	0.26	0.02	0.02	4	2.2	15	4	19.8
1967	1	0.01	0.07	0.53	0.07	<0.01	0.06	6	3.2	8	5.8	10.4
1967	5	<0.01	0.08	0.15	0.2	0.02	0.02	4	1.3	10	3.8	14.8
1967/68	1	<0.01	0.05	0.43	0.08	<0.01	0.05	5	3.1	8	6	10.6
1967/68	5	<0.01	0.24	0.09	0.25	0.02	0.02	3	1	8	3.3	14.4
1968	1	<0.01	0.05	0.43	0.05	<0.01	0.04	5	2.7	6	4.7	17.3
1968	5	<0.01	0.61	0.11	0.2	0.01	0.02	3	1	7	3	19.3
1968/69	1	0.01	0.07	0.5	0.03	0.01	0.07	6	3.2	17	4.6	19.9
1968/69	5	<0.01	0.05	0.08	0.23	0.01	0.02	4	1.2	10	3.1	19.4
1969	1	0.01	0.96	0.58	0.05	<0.01	0.07	6	4.2	15	5.9	20.6
1969	5	<0.01	0.08	0.11	0.21	0.02	0.02	3	1.2	12	3.4	17
1969/70	1	<0.01	0.06	0.45	0.05	0.01	0.06	6	2.9	8	5.6	18.2
1969/70	5	<0.01	0.09	0.08	0.26	0.02	0.02	3	1.1	14	3.7	14.8
1970	1	<0.01	0.06	0.59	0.07	<0.01	0.06	5	3	30	6.4	12.7
1970	5	<0.01	0.07	0.13	0.22	0.02	0.02	3	1.2	30	4	13.1
1970/71	1	0.01	0.05	0.59	0.09	<0.01	0.06	6	3.4	28	6	26.1
1970/71	5	<0.01	0.08	0.13	0.27	0.02	0.03	3	1.5	61	4.4	17.6
1971	1	<0.01	0.04	0.53	0.09	<0.01	0.06	6	2.8	31	5.9	16.4
1971	5	<0.01	0.06	0.11	0.16	0.02	0.02	3	1.5	23	3.7	13.3
1971/72	1	<0.01	0.04	0.44	0.08	<0.01	0.06	5	2.8	15	5.9	8.8
1971/72	5	<0.01	0.03	0.13	0.13	0.01	0.03	3	1.8	24	3.7	6.3
1972	1	<0.01	0.09	0.62	0.04	<0.01	0.08	7	3.1	17	5.4	14.8
1972	5	<0.01	0.06	0.17	0.14	0.02	0.03	3	3.3	17	4	22.3
1972/73	1	0.01	0.08	0.56	0.03	<0.01	0.07	6	3.7	14	4.7	24.5
1972/73	5	<0.01	0.13	0.08	0.24	0.02	0.02	3	1.2	15	2.6	21.1
1973	1	<0.01	0.28	0.49	0.04	<0.01	0.06	6	3	8	4.4	14.8

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1973	5	<0.01	0.11	0.16	0.17	0.02	0.02	3	1	11	2.6	18.2
1973/74	1	<0.01	0.05	0.56	0.06	<0.01	0.06	5	5.5	7	4.9	19.8
1973/74	5	<0.01	0.07	0.08	0.18	0.02	0.02	3	0.8	7	2.4	13.8
1974	1	<0.01	0.05	0.53	0.05	<0.01	0.06	5	2.6	9	4.3	17.4
1974	5	<0.01	0.12	0.15	0.24	0.02	0.02	3	1.5	14	4	20.3
1974/75	1	<0.01	0.05	0.53	0.07	<0.01	0.06	6	3.3	9	4.7	18.7
1974/75	5	<0.01	0.14	0.09	0.27	0.02	0.02	2	0.8	10	2.1	20.1
1975	1	<0.01	0.06	0.57	0.06	<0.01	0.07	6	3.3	10	4.6	25.9
1975	5	<0.01	0.13	0.14	0.3	0.02	0.02	3	1.1	9	2.4	28.6
1975/76	1	<0.01	0.05	0.57	0.08	<0.01	0.07	6	3.2	8	4.9	54.7
1975/76	5	<0.01	0.24	0.09	0.36	0.03	0.02	3	1.2	18	1.8	18.2
1976	1	<0.01	0.03	0.44	0.1	<0.01	0.05	5	2.9	9	4.4	18.2
1976	5	<0.01	0.07	0.14	0.23	0.02	0.02	3	1.3	38	2.4	119.2
1976/77	1	<0.01	0.03	0.45	0.11	<0.01	0.06	5	2.8	10	4.6	36.3
1976/77	5	<0.01	0.09	0.11	0.21	0.01	0.03	3	2.1	12	2.5	27.5
1977	1	<0.01	0.04	0.42	0.08	<0.01	0.06	5	2.9	32	4.8	52.6
1977	5	<0.01	0.17	0.13	0.19	0.02	0.03	4	1.4	21	3.2	19.1
1977/78	1	<0.01	0.05	0.5	0.04	<0.01	0.06	6	3.1	8	3.9	37.4
1977/78	5	<0.01	0.12	0.13	0.25	0.02	0.02	3	1.2	9	2.8	24.4
1978	1	<0.01	0.05	0.48	0.08	<0.01	0.07	7	3.4	11	5.2	51.4
1978	5	<0.01	0.21	0.09	0.21	0.02	0.03	3	1.6	9	3	20.1
1978/79	1	<0.01	0.06	0.46	0.03	0.01	0.06	6	3	28	4	35
1978/79	5	<0.01	0.12	0.1	0.28	0.03	0.02	3	2	36	4.2	32
1979	1	<0.01	0.06	0.57	0.04	<0.01	0.07	6	3.4	9	5	11
1979	5	<0.01	0.1	0.18	0.2	0.02	0.02	3	2.8	78	4.3	72
1979/80	1	0.01	0.07	0.56	0.04	<0.01	0.08	6	3.3	17	4.7	18
1979/80	5	<0.01	0.15	0.1	0.27	0.03	0.02	3	1.7	20	3.2	27
1980	1	<0.01	0.06	0.55	0.04	<0.01	0.07	6	3.6	23	4.5	20
1980	5	<0.01	0.14	0.16	0.22	0.03	0.02	4	1.3	7	3.6	18
1980/81	1	<0.01	0.06	0.62	0.08	<0.01	0.08	7	3.9	21	5.4	37
1980/81	5	<0.01	0.1	0.12	0.24	0.02	0.02	3	1.6	16	4.9	24
1982	1	0.01	0.09	0.6	0.03	<0.01	0.09	7	3.8	22	5.4	27
1982	5	<0.01	0.12	0.14	0.2	0.02	0.02	3	1.1	18	2.5	45
1982/83	1	<0.01	0.06	0.51	0.05	<0.01	0.08	7	3.6	7	5.1	21
1982/83	5	<0.01	0.1	0.09	0.23	0.02	0.02	3	1.2	21	3	23
1983	1	0.01	0.06	0.53	0.07	<0.01	0.07	6	3.7	14	5.7	26
1983	5	<0.01	0.05	0.14	0.2	0.02	0.02	4	1.3	24	3.6	27
1983/84	1	0.01	0.06	0.46	0.07	<0.01	0.07	6	3.6	22	6	16
1983/84	5	<0.01	0.13	0.1	0.22	0.03	0.02	3	1.5	32	4.4	21
1984	1	<0.01	0.06	0.46	0.06	<0.01	0.07	6	3.6	11	5.6	14
1984	5	<0.01	0.12	0.12	0.19	0.04	0.03	4	2.3	30	6.3	25
1984/85	1	<0.01	0.07	0.44	0.07	<0.01	0.07	6	3.5	14	5.7	16

Gyngoorda stem (Stem 1) - Nutrient analyses results.

1984/85	5	<0.01	0.07	0.11	0.23	0.07	0.03	3	2.9	57	24	20
1985	1	0.02	0.16	0.62	0.04	<0.01	0.08	6	3.6	27	5	30.8
1985	5	<0.01	0.21	0.12	0.21	0.02	0.02	3	1	11	1.8	23
1985/86	1	0.01	0.13	0.54	0.03	<0.01	0.07	6	3.9	8	4.2	44.3
1985/86	5	<0.01	0.17	0.09	0.26	0.02	0.02	3	1.2	4	1.7	22.8
1986	1	0.01	0.1	0.6	0.04	<0.01	0.08	6	4	223	6.8	54.8
1986	5	0.01	0.13	0.1	0.26	0.02	0.03	2	2.2	287	6.7	64.2
1986/87	1	0.01	0.1	0.68	0.05	<0.01	0.09	7	4.9	22	5	42.6
1986/87	5	0.01	0.14	0.11	0.32	0.02	0.02	3	1.6	40	3.4	32.4
1987	1	0.01	0.12	0.74	0.06	<0.01	0.1	8	4.4	20	5.2	51.4
1987	5	<0.01	0.12	0.11	0.27	0.02	0.02	3	0.9	16	2.6	21.7
1987/88	1	0.01	0.11	0.63	0.08	<0.01	0.09	7	5.1	26	5.6	41.9
1987/88	5	0.01	0.1	0.11	0.25	0.02	0.02	3	2.5	53	3.8	27.8
1988	1	0.01	0.12	0.6	0.06	<0.01	0.1	7	3.8	11	5.4	27.6
1988	5	<0.01	0.09	0.09	0.22	0.02	0.02	3	1.3	23	2.3	23.8

Poison Gully stem (Stem 2) - Nutrient analyses results

Year	cm section	P	K	Na	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
		%db	%db	%db	%db	%db	%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1928	1	<0.01	0.02	<0.01	0.24	0.09	0.04	5	3.1	38	6.4	8.6
1928	5	<0.01	<0.01	0.01	0.15	0.18	0.03	5	1.3	57	13.7	9.9
1928/29	1	<0.01	<0.01	<0.01	0.3	0.11	0.05	6	3.5	15	5.8	5.6
1928/29	5	<0.01	<0.01	0.01	0.12	0.16	0.03	5	1.4	27	8.5	8.7
1929	1	<0.01	<0.01	<0.01	0.19	0.1	0.04	5	3	16	6.2	3.4
1929	5	<0.01	<0.01	<0.01	0.08	0.17	0.02	4	1.3	8	9.6	3.9
1929/30	1	<0.01	<0.01	<0.01	0.25	0.12	0.04	5	3.1	10	5.8	3.6
1929/30	5	<0.01	<0.01	<0.01	0.08	0.23	0.03	4	1.7	18	5.6	3.7
1930	1	<0.01	0.01	<0.01	0.24	0.12	0.04	5	2.8	6	5.6	3.3
1930	5	<0.01	<0.01	<0.01	0.09	0.28	0.02	4	1	7	6.3	4.5
1930/31	1	<0.01	0.01	<0.01	0.24	0.13	0.04	6	2.9	8	5.3	7.2
1930/31	5	<0.01	<0.01	<0.01	0.1	0.24	0.02	4	0.9	9	7.2	5.4
1931	1	<0.01	0.01	<0.01	0.25	0.12	0.04	6	4	194	7.1	69.7
1931	5	<0.01	0.01	0.01	0.11	0.26	0.02	5	1	44	10.8	12.8
1931/32	1	<0.01	0.01	<0.01	0.25	0.13	0.04	6	3.5	19	5.5	5.8
1931/32	5	<0.01	<0.01	<0.01	0.11	0.24	0.03	4	1.5	15	7.4	25.6
1932	1	<0.01	0.01	<0.01	0.24	0.14	0.04	6	2.9	20	5.7	4.8
1932	5	<0.01	<0.01	<0.01	0.12	0.26	0.03	4	1.5	18	10.6	4.2
1932/33	1	<0.01	0.01	<0.01	0.25	0.15	0.04	5	2.8	6	5.5	2.6
1932/33	5	<0.01	<0.01	<0.01	0.1	0.24	0.03	3	1.3	6	7.9	3.4
1933	1	<0.01	0.02	<0.01	0.26	0.16	0.04	5	3	6	5.2	3.6
1933	5	<0.01	0.01	<0.01	0.11	0.21	0.02	5	1.5	6	6.9	5.2
1933/34	1	<0.01	0.01	<0.01	0.3	0.13	0.04	6	3	7	6.9	3.2
1933/34	5	<0.01	0.01	<0.01	0.12	0.2	0.02	4	1.6	6	7.3	3.1
1934	1	<0.01	0.01	<0.01	0.24	0.15	0.04	5	2.9	5	6	6.4
1934	5	<0.01	0.01	<0.01	0.13	0.19	0.03	4	1.2	10	7.9	9.8
1934/35	1	<0.01	0.01	<0.01	0.31	0.18	0.05	7	3.2	10	5.2	9.3
1934/35	5	<0.01	0.01	<0.01	0.11	0.27	0.03	5	1.3	20	6.2	7.2
1935	1	<0.01	0.01	<0.01	0.32	0.16	0.04	6	2.8	5	5.5	6.4
1935	5	<0.01	<0.01	<0.01	0.16	0.22	0.03	4	1.6	7	6.5	4.2
1935/36	1	<0.01	0.02	<0.01	0.31	0.17	0.04	6	2.7	10	5.9	5.3
1935/36	5	<0.01	0.01	<0.01	0.13	0.26	0.03	5	1.4	11	5.6	3.8
1936	1	<0.01	0.02	<0.01	0.26	0.14	0.05	6	3.2	4	5.5	3.7
1936	5	<0.01	0.02	0.01	0.11	0.19	0.03	4	1.1	7	10.4	6.1
1936/37	1	<0.01	0.01	<0.01	0.3	0.15	0.04	6	3	4	5.4	4
1936/37	5	<0.01	0.01	0.01	0.14	0.19	0.03	5	1.6	6	8	3.6
1937	1	<0.01	0.01	<0.01	0.22	0.12	0.04	6	2.9	5	6.6	3.2

Poison Gully stem (Stem 2) - Nutrient analyses results

1937	5	<0.01	0.01	<0.01	0.12	0.28	0.03	5	1.1	5	10.6	3.1
1937/38	1	<0.01	0.01	<0.01	0.3	0.13	0.04	6	3.4	4	5.8	3.7
1937/38	5	<0.01	0.01	0.01	0.17	0.23	0.03	5	1.6	6	14.6	4.9
1938	1	<0.01	0.01	<0.01	0.28	0.12	0.04	6	3.1	4	5.3	3.4
1938	5	<0.01	0.01	0.01	0.13	0.24	0.03	5	1.2	10	16.2	6.8
1938/39	1	<0.01	0.02	<0.01	0.32	0.13	0.04	6	3.2	5	5.5	2.6
1938/39	5	<0.01	0.02	<0.01	0.14	0.22	0.03	5	2.1	8	10.4	4.4
1939	1	<0.01	0.01	<0.01	0.24	0.15	0.05	6	2.9	4	5.1	7
1939	5	<0.01	0.02	0.01	0.12	0.25	0.03	5	1.4	9	9.6	7.7
1939/40	1	<0.01	0.01	<0.01	0.31	0.15	0.05	6	3.3	10	5.4	2.8
1939/40	5	<0.01	0.01	<0.01	0.14	0.22	0.03	5	1.6	7	7	6.8
1940	1	<0.01	0.01	<0.01	0.27	0.15	0.04	6	2.9	4	5.5	3
1940	5	<0.01	0.01	0.01	0.13	0.29	0.03	5	1.3	10	10.1	5.9
1940/41	1	<0.01	0.02	<0.01	0.29	0.14	0.04	6	3.6	3	5.6	3.6
1940/41	5	<0.01	0.01	<0.01	0.12	0.22	0.03	4	1.7	9	5.2	3.9
1941	1	<0.01	0.01	<0.01	0.22	0.15	0.04	5	3	14	5.5	3.2
1941	5	<0.01	0.01	<0.01	0.11	0.18	0.02	4	1.1	6	8.1	5.8
1941/42	1	<0.01	0.01	<0.01	0.26	0.16	0.04	6	3	6	5.7	5.1
1941/42	5	<0.01	0.01	<0.01	0.1	0.24	0.03	4	1.6	7	4.9	4.4
1942	1	<0.01	0.01	<0.01	0.23	0.13	0.04	6	2.8	8	5.7	3.9
1942	5	<0.01	0.01	<0.01	0.09	0.28	0.03	4	1.2	8	4.8	4.3
1942/43	1	<0.01	0.01	<0.01	0.27	0.12	0.04	6	2.9	11	6.4	3.1
1942/43	5	<0.01	0.01	<0.01	0.11	0.24	0.03	4	1.3	7	8.5	7.9
1943	1	<0.01	0.01	<0.01	0.28	0.12	0.04	6	3.1	6	6.1	3.5
1943	5	<0.01	0.01	<0.01	0.13	0.26	0.03	4	1.1	13	11	5.3
1943/44	1	<0.01	0.01	<0.01	0.3	0.13	0.04	6	3.3	30	8	5.2
1943/44	5	<0.01	0.01	0.01	0.11	0.34	0.04	4	1.6	11	5.8	18.1
1944	1	<0.01	0.01	<0.01	0.29	0.12	0.04	6	3.4	12	5.7	4.4
1944	5	<0.01	0.01	0.01	0.1	0.37	0.04	5	1.5	13	5.1	4.8
1944/45	1	<0.01	0.01	<0.01	0.29	0.13	0.04	6	3.4	7	5.2	5.2
1944/45	5	<0.01	0.01	<0.01	0.12	0.26	0.03	4	1.6	7	3.4	5
1945	1	<0.01	0.01	<0.01	0.27	0.17	0.04	6	3.1	9	5.1	4.8
1945	5	<0.01	0.01	<0.01	0.13	0.28	0.03	4	1.1	9	3.7	3.6
1945/46	1	<0.01	0.01	<0.01	0.33	0.18	0.05	6	3	9	5.8	5.1
1945/46	5	<0.01	<0.01	<0.01	0.1	0.22	0.04	4	1.4	10	3.3	4.1
1946	1	<0.01	0.02	<0.01	0.26	0.19	0.05	6	2.8	6	5.3	6.3
1946	5	<0.01	0.01	<0.01	0.09	0.26	0.03	4	0.9	10	4.6	5.6
1946/47	1	<0.01	<0.01	<0.01	0.25	0.2	0.04	6	3.2	6	5.2	4.9
1946/47	5	<0.01	<0.01	<0.01	0.09	0.25	0.03	4	1.7	10	4.4	12.4
1947	1	<0.01	0.01	<0.01	0.24	0.2	0.04	6	8.3	9	6	10.3

Poison Gully stem (Stem 2) - Nutrient analyses results

1947	5	<0.01	0.01	0.01	0.12	0.26	0.03	4	1.3	16	6.5	5.9
1947/48	1	<0.01	0.01	<0.01	0.28	0.19	0.05	6	3.1	9	5.9	5
1947/48	5	<0.01	<0.01	<0.01	0.12	0.21	0.03	3	1.5	8	5	6.5
1948	1	<0.01	0.01	<0.01	0.23	0.19	0.04	6	2.9	8	5.8	6.1
1948	5	<0.01	0.01	<0.01	0.12	0.19	0.04	4	1.4	13	7.2	5.8
1948/49	1	<0.01	0.01	<0.01	0.27	0.16	0.05	6	3.3	9	7	5.9
1948/49	5	<0.01	0.01	<0.01	0.09	0.26	0.04	4	1.4	10	5.2	12.6
1949	1	<0.01	0.01	<0.01	0.26	0.14	0.05	6	3.5	8	6.5	9
1949	5	<0.01	0.01	0.01	0.09	0.28	0.04	4	1.1	10	6.4	13.4
1949/50	1	<0.01	0.02	<0.01	0.3	0.14	0.04	6	3.8	8	6.9	8.2
1949/50	5	<0.01	0.01	<0.01	0.13	0.26	0.03	4	1.7	6	3.8	6.1
1950	1	<0.01	0.01	<0.01	0.29	0.17	0.05	6	3.7	17	6	7.4
1950	5	<0.01	0.01	0.01	0.11	0.4	0.03	4	1.7	19	5.8	11.4
1950/51	1	<0.01	0.01	<0.01	0.31	0.17	0.04	6	3.2	6	5.8	4
1950/51	5	<0.01	0.01	<0.01	0.12	0.28	0.03	4	1.3	8	3.5	3.8
1951	1	<0.01	0.01	<0.01	0.27	0.16	0.04	6	3.5	20	6.1	6.9
1951	5	<0.01	0.01	0.01	0.13	0.32	0.03	4	1.9	26	12.2	10.1
1951/52	1	<0.01	0.01	<0.01	0.32	0.18	0.04	5	3.2	5	6.2	4.3
1951/52	5	<0.01	<0.01	<0.01	0.12	0.22	0.03	3	1.7	7	3.7	2.4
1952	1	<0.01	0.01	<0.01	0.24	0.18	0.05	6	3.1	5	5.5	5
1952	5	<0.01	0.01	0.01	0.14	0.25	0.03	4	1.6	13	24.1	7.3
1952/53	1	<0.01	0.01	<0.01	0.28	0.16	0.05	5	3.3	7	6.2	5.4
1952/53	5	<0.01	<0.01	<0.01	0.11	0.18	0.03	3	1.6	7	5.7	4.8
1953	1	<0.01	0.01	<0.01	0.25	0.17	0.04	6	3.2	22	5.8	7.1
1953	5	<0.01	0.01	0.01	0.11	0.25	0.03	4	1.5	14	11.1	5.4
1953/54	1	<0.01	0.01	<0.01	0.3	0.15	0.05	6	3.3	8	6.2	7.4
1953/54	5	<0.01	<0.01	<0.01	0.11	0.22	0.03	4	1.3	7	7.5	5.5
1954	1	<0.01	0.01	<0.01	0.25	0.17	0.05	6	3.1	7	6.3	5
1954	5	<0.01	0.01	0.01	0.12	0.28	0.04	4	1	13	12.9	7.3
1954/55	1	<0.01	0.01	<0.01	0.29	0.2	0.05	6	3.2	9	5.8	4
1954/55	5	<0.01	0.01	<0.01	0.11	0.24	0.03	4	1.8	9	5.8	6.7
1955	1	<0.01	0.01	<0.01	0.24	0.16	0.04	6	3.2	7	5.4	5.2
1955	5	<0.01	0.01	<0.01	0.11	0.27	0.03	4	1	11	7.1	8
1955/56	1	<0.01	0.02	<0.01	0.32	0.16	0.04	6	3.1	6	5.7	5.4
1955/56	5	<0.01	0.01	<0.01	0.12	0.24	0.03	4	1.3	13	5	6
1956	1	<0.01	0.02	<0.01	0.27	0.18	0.04	6	3.6	16	5.8	5.6
1956	5	<0.01	0.01	<0.01	0.11	0.24	0.03	4	1.6	40	4.3	8.1
1956/57	1	<0.01	0.02	<0.01	0.29	0.17	0.04	6	3.2	17	6	7
1956/57	5	<0.01	<0.01	<0.01	0.1	0.21	0.03	4	1.6	8	3.2	8.8
1957	1	<0.01	0.01	<0.01	0.25	0.2	0.04	5	3	7	5.7	12.3

Poison Gully stem (Stem 2) - Nutrient analyses results

1957	5	<0.01	0.01	<0.01	0.11	0.32	0.03	4	1	20	6.2	11.1
1957/58	1	<0.01	0.01	<0.01	0.33	0.24	0.05	6	3.1	6	6.4	8.2
1957/58	5	<0.01	<0.01	<0.01	0.1	0.28	0.03	4	1.3	7	5.2	5.4
1958	1	<0.01	0.01	<0.01	0.28	0.22	0.05	6	3	11	7	7.7
1958	5	<0.01	<0.01	<0.01	0.1	0.29	0.03	4	1	12	4.9	11.5
1958/59	1	<0.01	0.02	<0.01	0.27	0.14	0.05	6	2.9	7	7.3	5.2
1958/59	5	<0.01	0.01	<0.01	0.09	0.17	0.03	4	1.5	22	5.1	6.4
1959	1	<0.01	0.01	<0.01	0.29	0.18	0.05	6	3.2	10	6.3	8.2
1959	5	<0.01	0.01	0.01	0.12	0.31	0.04	4	1	15	5.2	11
1959/60	1	<0.01	0.02	<0.01	0.31	0.15	0.05	5	3.3	8	7.3	6.3
1959/60	5	<0.01	<0.01	0.01	0.12	0.33	0.04	4	1.5	12	5.7	11.4
1960	1	<0.01	0.02	<0.01	0.31	0.16	0.05	6	3	6	6.4	4.9
1960	5	<0.01	0.01	0.01	0.11	0.39	0.03	4	1.2	13	5.1	10.4
1960/61	1	<0.01	0.03	<0.01	0.35	0.14	0.05	6	3.5	18	6.1	6.1
1960/61	5	<0.01	0.01	<0.01	0.14	0.27	0.04	4	1.8	7	5.7	6.2
1961	1	<0.01	0.02	<0.01	0.26	0.15	0.05	6	3.2	8	5.6	4.3
1961	5	<0.01	0.01	0.01	0.15	0.31	0.03	4	1.3	9	6	7.6
1961/62	1	<0.01	0.01	<0.01	0.33	0.18	0.05	6	3.5	6	5.2	3.7
1961/62	5	<0.01	0.01	0.01	0.14	0.29	0.03	5	1.8	10	5.8	12.4
1962	1	<0.01	<0.01	<0.01	0.26	0.16	0.05	5	3.2	4	5	4.8
1962	5	<0.01	0.02	0.01	0.16	0.31	0.03	4	1	13	8.5	10.4
1962/63	1	<0.01	0.01	0.01	0.15	0.26	0.03	4	1.4	15	7.5	7.5
1962/63	5	<0.01	0.02	<0.01	0.32	0.17	0.06	6	3.2	15	6	7.6
1963	1	<0.01	0.02	<0.01	0.26	0.18	0.06	6	3.4	8	5.9	6.5
1963	5	<0.01	0.01	0.01	0.13	0.29	0.03	4	1.5	15	6.8	8.5
1963/64	1	<0.01	0.01	<0.01	0.3	0.19	0.06	6	3.2	6	5.4	3.8
1963/64	5	<0.01	0.01	<0.01	0.11	0.26	0.04	4	1.3	9	5.3	7.6
1964	1	<0.01	0.02	<0.01	0.24	0.16	0.05	6	3	11	5.7	5.1
1964	5	<0.01	0.01	0.01	0.13	0.3	0.03	4	1	23	6.5	11.4
1964/65	1	<0.01	0.02	<0.01	0.3	0.16	0.05	6	3.3	4	6.1	5.3
1964/65	5	<0.01	0.01	0.01	0.12	0.26	0.04	4	1.4	13	5.6	9.8
1965	1	<0.01	0.02	<0.01	0.23	0.15	0.05	6	3	4	5.8	7
1965	5	<0.01	0.01	0.01	0.1	0.28	0.03	4	1.1	25	5.3	23.1
1965/66	1	<0.01	0.02	<0.01	0.26	0.15	0.05	6	3.3	5	5.9	6.9
1965/66	5	<0.01	0.01	<0.01	0.11	0.24	0.03	4	2.4	11	4.5	10.6
1966	1	<0.01	0.03	<0.01	0.23	0.15	0.05	6	3.1	6	5.9	9.2
1966	5	<0.01	0.01	0.01	0.11	0.28	0.03	4	1.2	11	5.2	8.8
1966/67	1	<0.01	0.02	<0.01	0.28	0.16	0.05	6	8.1	9	6.1	9.1
1966/67	5	<0.01	<0.01	<0.01	0.09	0.24	0.03	4	1.6	11	5	5.3
1967	1	<0.01	0.02	<0.01	0.23	0.18	0.05	7	3.6	9	5.9	6.1

Poison Gully stem (Stem 2) - Nutrient analyses results

1967	5	<0.01	0.01	<0.01	0.1	0.29	0.04	4	1.5	12	5.7	6.6
1967/68	1	<0.01	0.02	<0.01	0.26	0.16	0.05	6	3.3	4	5.8	4.4
1967/68	5	<0.01	0.01	<0.01	0.08	0.28	0.04	4	1.6	10	5.3	5.8
1968	1	<0.01	0.03	<0.01	0.22	0.14	0.05	6	3.3	20	6.1	8.5
1968	5	<0.01	0.01	<0.01	0.11	0.26	0.03	4	1.2	8	4.7	9.2
1968/69	1	<0.01	0.03	<0.01	0.29	0.17	0.05	6	3.4	5	5.9	7
1968/69	5	<0.01	<0.01	<0.01	0.13	0.22	0.03	4	1.5	8	3.6	7
1969	1	<0.01	0.04	<0.01	0.23	0.16	0.05	6	3.1	6	5.9	5.2
1969	5	<0.01	0.01	0.01	0.12	0.28	0.03	4	0.8	11	11.5	8.9
1969/70	1	<0.01	0.03	<0.01	0.29	0.16	0.05	6	3.1	8	6.1	5.5
1969/70	5	<0.01	<0.01	<0.01	0.1	0.22	0.03	4	1.9	8	5.1	5.3
1970	1	<0.01	0.02	<0.01	0.21	0.18	0.06	6	3.2	15	5.4	6.7
1970	5	<0.01	0.01	0.01	0.12	0.3	0.03	4	1.2	10	8.9	10.5
1970/71	1	<0.01	0.02	<0.01	0.28	0.18	0.05	6	3.4	6	5.8	5.9
1970/71	5	<0.01	0.01	<0.01	0.12	0.25	0.04	3	1.5	12	6	7.6
1971	1	<0.01	0.03	<0.01	0.3	0.17	0.06	6	3.1	5	6.4	5.8
1971	5	<0.01	0.01	0.01	0.12	0.31	0.04	5	0.8	18	9.5	8.5
1971/72	1	<0.01	0.04	<0.01	0.32	0.19	0.06	6	3	8	6.5	9.5
1971/72	5	<0.01	0.01	<0.01	0.13	0.25	0.04	4	1.4	11	4.2	5.2
1972	1	<0.01	0.04	<0.01	0.27	0.17	0.06	6	3.4	11	6.4	10.6
1972	5	<0.01	0.01	0.01	0.12	0.33	0.04	4	1.1	20	5.2	12.7
1972/73	1	<0.01	0.03	<0.01	0.29	0.18	0.05	6	3	5	6.1	6
1972/73	5	<0.01	0.01	<0.01	0.12	0.29	0.04	4	1.3	11	4.8	7.2
1973	1	<0.01	0.04	<0.01	0.25	0.16	0.06	6	3.1	5	6.3	7.9
1973	5	<0.01	0.02	0.01	0.1	0.28	0.04	4	1	10	5.4	8.9
1973/74	1	<0.01	0.03	<0.01	0.33	0.18	0.06	6	3.2	4	6.2	8
1973/74	5	<0.01	0.01	<0.01	0.1	0.24	0.03	3	1.2	18	4	57.3
1974	1	<0.01	0.04	<0.01	0.25	0.17	0.05	6	3	7	6.2	10.1
1974	5	<0.01	0.01	<0.01	0.11	0.28	0.03	4	0.9	12	5	11.4
1974/75	1	<0.01	0.03	<0.01	0.28	0.18	0.05	6	3.2	7	6.2	7.2
1974/75	5	<0.01	0.02	<0.01	0.1	0.29	0.04	4	1.1	17	5.3	7
1975	1	<0.01	0.03	<0.01	0.27	0.21	0.05	6	3	6	6	9.1
1975	5	<0.01	0.02	<0.01	0.12	0.38	0.03	4	1	19	3.6	9.2
1975/76	1	<0.01	0.04	<0.01	0.32	0.2	0.06	6	3.1	5	6.6	7.1
1975/76	5	<0.01	0.02	<0.01	0.11	0.36	0.04	3	1.6	38	4.2	15.2
1976	1	<0.01	0.04	<0.01	0.29	0.17	0.05	6	3.1	6	6.5	10.2
1976	5	<0.01	0.02	<0.01	0.11	0.42	0.04	4	1	11	4.5	12.3
1976/77	1	<0.01	0.04	<0.01	0.31	0.21	0.05	6	2.8	7	6.5	8.9
1976/77	5	<0.01	0.02	<0.01	0.12	0.42	0.03	4	0.7	14	4.5	12.5
1977	1	<0.01	0.03	<0.01	0.3	0.22	0.05	6	2.8	6	6.2	7.3

Poison Gully stem (Stem 2) - Nutrient analyses results

1977	5	<0.01	0.02	<0.01	0.1	0.45	0.04	4	1	11	4.4	8.4
1977/78	1	<0.01	0.04	<0.01	0.28	0.24	0.05	6	2.9	7	6	10.7
1977/78	5	<0.01	0.01	<0.01	0.13	0.31	0.03	4	0.6	14	4.5	9.2
1978	1	<0.01	0.04	<0.01	0.27	0.19	0.05	6	2.9	7	6.3	7.5
1978	5	<0.01	0.02	<0.01	0.11	0.3	0.02	4	0.9	39	4.5	17.9
1978/79	1	<0.01	0.04	<0.01	0.26	0.2	0.05	6	2.9	6	6.5	7.8
1978/79	5	<0.01	0.01	<0.01	0.12	0.39	0.03	4	0.8	10	4.5	8.9

Amphion stem (Stem 3) - Nutrient analyses results.

Year	cm length	P	K	Na	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
		%db	%db	%db	%db	%db	%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1931	1	<0.01	0.06	0.01	0.13	0.01	0.07	5	3.6	15	4.3	6.6
1931	5	<0.01	0.01	0.02	0.21	0.11	0.03	4	2.6	35	6.6	6.2
1931/32	1	<0.01	0.1	0.01	0.17	0.02	0.07	6	3.8	18	4.4	11.6
1931/32	5	<0.01	0.01	0.02	0.2	0.14	0.03	4	2.3	133	5.8	14.3
1932	1	<0.01	0.08	<0.01	0.17	0.02	0.08	5	3.7	19	4.4	7.1
1932	5	<0.01	0.01	0.02	0.28	0.16	0.03	4	3.5	545	12.8	21.9
1932/33	1	<0.01	0.08	<0.01	0.18	0.02	0.07	5	6.5	16	4.3	10
1932/33	5	<0.01	0.01	0.02	0.28	0.14	0.03	4	2.4	54	8.1	11.2
1933	1	<0.01	0.08	<0.01	0.19	0.02	0.08	6	3.7	16	4.5	6.9
1933	5	<0.01	0.01	0.02	0.31	0.14	0.03	4	2.6	69	9.7	8.7
1933/34	1	<0.01	0.05	<0.01	0.18	0.01	0.08	6	4.2	16	4.5	10.1
1933/34	5	<0.01	0.01	0.03	0.36	0.14	0.03	4	3	38	11.7	12.6
1934	1	<0.01	0.06	<0.01	0.18	0.01	0.07	5	4	15	4.4	8
1934	5	<0.01	0.01	0.03	0.3	0.13	0.03	4	2.8	32	11.6	6.4
1934/35	1	<0.01	0.1	<0.01	0.16	0.01	0.07	5	3.7	14	4.4	7.3
1934/35	5	<0.01	0.01	0.03	0.27	0.13	0.03	4	2.4	60	10.3	8.2
1935	1	<0.01	0.09	0.01	0.18	0.01	0.07	5	3.6	24	4.6	10.1
1935	5	<0.01	0.01	0.02	0.29	0.13	0.03	3	2.4	89	9.5	16.2
1935/36	1	<0.01	0.13	0.01	0.19	0.02	0.08	6	4	15	4.6	10.8
1935/36	5	<0.01	0.01	0.02	0.28	0.16	0.03	4	2	64	8.3	8.5
1936	1	<0.01	0.08	0.01	0.16	0.02	0.09	6	3.8	18	4.7	12.8
1936	5	<0.01	0.01	0.01	0.28	0.18	0.03	3	1.7	145	8.8	18.4
1936/37	1	<0.01	0.09	0.01	0.14	0.01	0.08	5	3.7	18	4.5	10.8
1936/37	5	<0.01	0.01	0.01	0.24	0.15	0.03	3	2.6	119	8.5	8.2
1937	1	<0.01	0.11	0.01	0.16	0.02	0.07	4	3.4	20	4.6	10.7
1937	5	<0.01	0.01	0.02	0.27	0.14	0.03	3	2.6	69	11.1	21
1937/38	1	<0.01	0.13	<0.01	0.15	0.01	0.08	5	3.6	15	4.3	8.8
1937/38	5	<0.01	0.01	0.01	0.21	0.11	0.03	3	1.8	72	7.7	13.4
1938	1	<0.01	0.09	0.01	0.15	0.01	0.07	5	3.6	11	4.3	6.8
1938	5	<0.01	0.01	0.02	0.31	0.13	0.03	3	2.3	67	11.9	7.5
1938/39	1	<0.01	0.11	<0.01	0.14	0.01	0.07	5	4.1	12	4.4	6.6
1938/39	5	<0.01	0.01	0.01	0.21	0.12	0.03	3	3.4	52	6.3	7.2
1939	1	<0.01	0.1	0.01	0.18	0.01	0.07	5	3.5	11	4.3	5
1939	5	<0.01	<0.01	0.02	0.3	0.22	0.02	4	1.4	38	6.9	6.3
1939/40	1	<0.01	0.07	<0.01	0.14	0.01	0.08	5	3.8	17	4.4	8.6
1939/40	5	<0.01	0.01	0.02	0.24	0.19	0.03	4	2.4	55	5	8.3
1940	1	<0.01	0.1	0.01	0.15	0.02	0.06	4	3.5	64	4.8	2.1

Amphion stem (Stem 3) - Nutrient analyses results.

1940	5	<0.01	<0.01	0.02	0.29	0.17	0.03	3	8.4	12	5.7	7.4
1940/41	1	<0.01	0.18	0.01	0.17	0.01	0.07	5	5.4	<10	4.5	2.6
1940/41	5	<0.01	0.01	0.01	0.23	0.13	0.03	4	2.9	50	3.6	2.6
1941	1	<0.01	0.13	<0.01	0.13	0.01	0.07	4	3.9	<10	4.7	1.8
1941	5	<0.01	0.01	0.01	0.21	0.21	0.02	4	1.5	13	6.1	2.5
1941/42	1	<0.01	0.18	0.01	0.15	0.01	0.08	5	4.2	<10	4.7	2.4
1941/42	5	<0.01	<0.01	0.01	0.22	0.17	0.03	3	1.4	81	4.1	2.6
1942	1	<0.01	0.1	<0.01	0.17	0.01	0.07	5	3.7	<10	4.3	1.5
1942	5	<0.01	<0.01	0.02	0.28	0.21	0.03	4	9.1	33	6.3	6.9
1942/43	1	<0.01	0.16	0.01	0.14	0.01	0.06	5	3.7	<10	4.6	2
1942/43	5	<0.01	<0.01	0.01	0.18	0.14	0.03	4	1.2	30	3.1	2.4
1943	1	<0.01	0.14	<0.01	0.14	0.01	0.07	5	16.9	<10	4.4	11.3
1943	5	<0.01	0.01	0.02	0.3	0.16	0.02	4	2.1	17	7.8	3.2
1943/44	1	<0.01	0.18	0.01	0.14	0.01	0.07	5	4.9	<10	4.2	3.2
1943/44	5	<0.01	0.01	0.02	0.21	0.13	0.03	4	3.3	26	5.3	3.8
1944	1	<0.01	0.1	0.01	0.13	0.01	0.06	4	3.6	<10	4.8	7.1
1944	5	<0.01	0.01	0.01	0.26	0.15	0.03	3	1.7	20	5.9	16.7
1944/45	1	<0.01	0.19	0.01	0.13	0.01	0.07	5	3.6	<10	4.6	7
1944/45	5	<0.01	0.01	0.01	0.18	0.1	0.03	3	2.7	13	3.2	4.9
1945	1	<0.01	0.1	0.01	0.13	0.01	0.07	5	3.7	<10	4.4	7.6
1945	5	<0.01	0.01	0.01	0.27	0.14	0.02	3	1.4	14	5.5	4.6
1945/46	1	<0.01	0.14	0.01	0.13	0.01	0.06	4	3.4	<10	4.2	6.2
1945/46	5	<0.01	0.01	0.01	0.2	0.11	0.02	4	1.3	21	4.2	4.3
1946	1	<0.01	0.1	0.01	0.15	0.01	0.06	4	3.5	<10	4.3	6.3
1946	5	<0.01	0.01	0.01	0.27	0.13	0.02	4	2	11	5.9	4.5
1946/47	1	<0.01	0.11	0.01	0.12	0.01	0.06	4	3.4	<10	4.2	2.6
1946/47	5	<0.01	0.01	0.02	0.23	0.14	0.03	4	3.9	67	7.3	3.4
1947	1	<0.01	0.08	0.01	0.14	0.01	0.06	4	4	<10	4	2.1
1947	5	<0.01	0.01	0.02	0.28	0.15	0.03	4	1.7	23	6.8	1.7
1947/48	1	<0.01	0.08	<0.01	0.1	0.01	0.06	4	4.6	<10	4.8	2.1
1947/48	5	<0.01	0.01	0.01	0.19	0.12	0.02	4	1.5	54	5	1.6
1948	1	<0.01	0.05	<0.01	0.11	0.01	0.05	3	3.8	<10	4	1.6
1948	5	<0.01	0.01	0.02	0.26	0.13	0.02	3	1.4	35	6	5
1948/49	1	<0.01	0.07	<0.01	0.11	0.02	0.05	4	7.2	<10	4.1	3.9
1948/49	5	<0.01	0.01	0.01	0.23	0.1	0.02	3	1.7	51	5	2.2
1949	1	<0.01	0.07	<0.01	0.12	0.01	0.06	4	3.5	48	4.8	1.2
1949	5	<0.01	0.01	0.02	0.28	0.14	0.02	4	1.6	59	7.2	2.2
1949/50	1	<0.01	0.1	<0.01	0.11	0.01	0.06	4	5.1	<10	4.2	2.6
1949/50	5	<0.01	0.01	0.01	0.2	0.1	0.03	3	1.4	50	4.8	1.7
1950	1	<0.01	0.1	<0.01	0.12	0.01	0.08	4	3.8	<10	4.3	1.8

Amphion stem (Stem 3) - Nutrient analyses results.

1950	5	<0.01	0.01	0.01	0.22	0.14	0.02	4	0.8	<10	5.1	3.1
1950/51	1	<0.01	0.1	<0.01	0.13	0.01	0.08	4	4.1	<10	3.9	2
1950/51	5	<0.01	<0.01	0.01	0.21	0.12	0.03	3	1.3	<10	3.6	1.1
1951	1	<0.01	0.11	0.01	0.16	0.01	0.07	4	5.4	<10	4.6	2.7
1951	5	<0.01	0.01	0.01	0.24	0.15	0.02	3	1.8	29	4.3	2
1951/52	1	<0.01	0.09	<0.01	0.16	0.01	0.09	5	5.2	<10	4.4	3.6
1951/52	5	<0.01	0.01	0.01	0.18	0.15	0.03	3	1.6	<10	2.8	2.1
1952	1	0.01	0.08	<0.01	0.17	0.01	0.1	5	4.6	11	4.8	4.5
1952	5	<0.01	0.01	0.01	0.24	0.17	0.03	3	2.3	<10	3.9	3.5
1952/53	1	<0.01	0.08	<0.01	0.16	0.01	0.09	5	4.4	<10	4.7	3.2
1952/53	5	<0.01	0.01	0.01	0.2	0.11	0.03	4	3.6	<10	2.9	5.6
1953	1	<0.01	0.08	<0.01	0.18	0.01	0.11	6	9.9	<10	4.6	7.8
1953	5	<0.01	0.01	0.01	0.26	0.2	0.03	4	1.5	22	4.8	3.5
1953/54	1	<0.01	0.12	<0.01	0.17	0.01	0.1	5	3.8	<10	4.5	2.5
1953/54	5	<0.01	0.01	0.01	0.21	0.1	0.03	3	5.2	24	3.1	4.7
1954	1	<0.01	0.05	<0.01	0.16	0.01	0.1	6	4	<10	4.7	0.7
1954	5	<0.01	0.01	0.01	0.26	0.19	0.03	4	2.1	14	5	2.6
1954/55	1	<0.01	0.1	<0.01	0.15	0.01	0.09	5	4.9	<10	4.3	2.7
1954/55	5	<0.01	<0.01	0.01	0.16	0.11	0.04	4	3.9	22	4.5	3.8
1955	1	<0.01	0.08	<0.01	0.16	0.01	0.1	6	4.1	<10	4.4	1.6
1955	5	<0.01	<0.01	0.01	0.25	0.18	0.03	3	2.1	24	6.2	2.6
1955/56	1	<0.01	0.12	<0.01	0.15	0.01	0.1	6	11.7	<10	4.4	6.6
1955/56	5	<0.01	<0.01	<0.01	0.22	0.14	0.03	3	1.3	22	2.5	1.2
1956	1	<0.01	0.09	<0.01	0.18	0.01	0.11	6	4.5	<10	4.4	1.2
1956	5	<0.01	<0.01	<0.01	0.26	0.19	0.03	4	1.3	15	3.3	0.8
1956/57	1	0.01	0.14	<0.01	0.16	0.01	0.13	6	4.2	<10	4.4	1.3
1956/57	5	<0.01	<0.01	<0.01	0.23	0.17	0.03	4	1.3	<10	2.8	1.9
1957	1	0.01	0.07	<0.01	0.18	0.01	0.13	6	4.4	<10	4.2	1.3
1957	5	<0.01	<0.01	<0.01	0.27	0.26	0.03	4	1	<10	3.7	4.2
1957/58	1	<0.01	0.27	<0.01	0.16	0.01	0.12	6	10.1	<10	4.3	5.6
1957/58	5	<0.01	0.01	<0.01	0.21	0.12	0.03	4	6.6	14	2.5	11.1
1958	1	<0.01	0.04	<0.01	0.16	0.01	0.1	6	4.8	<10	4.5	3.4
1958	5	<0.01	0.01	<0.01	0.23	0.22	0.03	4	2.8	<10	4.2	2.6
1958/59	1	<0.01	0.05	<0.01	0.14	0.01	0.1	6	5.8	<10	4.4	3
1958/59	5	<0.01	<0.01	<0.01	0.22	0.12	0.04	4	6.7	24	3.2	4.7
1959	1	<0.01	0.05	<0.01	0.18	0.01	0.1	5	4.6	<10	4.4	19.9
1959	5	<0.01	<0.01	0.01	0.24	0.22	0.03	4	2.7	11	3.5	10.4
1959/60	1	<0.01	0.05	<0.01	0.14	0.01	0.1	6	24.5	44	4.6	19.8
1959/60	5	<0.01	<0.01	<0.01	0.22	0.14	0.03	3	1.3	<10	2.1	3.6
1960	1	<0.01	0.05	<0.01	0.16	0.02	0.09	4	3.7	<10	4.3	11

Amphion stem (Stem 3) - Nutrient analyses results.

1960	5	<0.01	0.01	0.01	0.23	0.18	0.03	4	1.2	<10	2.8	2.9
1960/61	1	0.01	0.06	<0.01	0.16	0.01	0.12	6	4.1	<10	4.5	4.4
1960/61	5	<0.01	<0.01	<0.01	0.17	0.12	0.04	3	1.6	<10	2.5	2.4
1961	1	<0.01	0.05	<0.01	0.17	0.01	0.1	6	6.5	<10	4.4	4.8
1961	5	<0.01	<0.01	<0.01	0.24	0.17	0.03	4	2.4	<10	3.1	2.8
1961/62	1	0.01	0.06	<0.01	0.16	0.01	0.12	6	5.5	<10	4.3	6.2
1961/62	5	<0.01	<0.01	<0.01	0.21	0.12	0.04	3	6.9	<10	2.2	18.1
1962	1	<0.01	0.06	<0.01	0.15	0.01	0.11	5	6	13	4.4	10.7
1962	5	<0.01	<0.01	0.01	0.19	0.19	0.03	3	2.1	<10	2.6	11.6
1962/63	1	<0.01	0.05	<0.01	0.15	0.01	0.1	5	4	<10	4.3	4.9
1962/63	5	<0.01	<0.01	<0.01	0.2	0.13	0.03	2	2.2	<10	2.2	4
1963	1	0.01	0.08	<0.01	0.16	0.01	0.12	6	26.2	<10	4.6	21
1963	5	<0.01	<0.01	<0.01	0.21	0.2	0.03	3	3.3	18	3.4	7.9
1963/64	1	<0.01	0.05	<0.01	0.18	0.01	0.11	5	6	<10	4.4	6.3
1963/64	5	<0.01	<0.01	<0.01	0.22	0.14	0.04	3	9.2	37	3.2	21.3
1964	1	<0.01	0.06	<0.01	0.19	0.01	0.11	6	6.7	<10	4.3	19.1
1964	5	<0.01	<0.01	<0.01	0.25	0.2	0.03	3	1.8	<10	3.9	2.8
1964/65	1	0.01	0.07	<0.01	0.17	0.01	0.11	6	9	<10	4.3	9.6
1964/65	5	<0.01	<0.01	<0.01	0.22	0.14	0.04	3	1.8	28	2.4	7.8
1965	1	0.01	0.06	<0.01	0.19	0.01	0.11	5	4.3	<10	4.3	3.6
1965	5	<0.01	0.01	<0.01	0.23	0.17	0.04	3	3.1	<10	2.6	7.4
1965/66	1	0.01	0.07	<0.01	0.18	0.01	0.12	6	5.2	<10	4.4	2.3
1965/66	5	<0.01	<0.01	<0.01	0.23	0.12	0.04	3	2	16	2.1	3.3
1966	1	0.01	0.07	<0.01	0.19	0.01	0.13	6	5.8	<10	4.6	2.6
1966	5	<0.01	<0.01	<0.01	0.24	0.14	0.03	3	2.9	15	2.5	3.6
1966/67	1	0.01	0.09	<0.01	0.19	0.01	0.14	7	6.5	10	4.4	5.6
1966/67	5	<0.01	<0.01	<0.01	0.18	0.1	0.04	3	2.3	14	2	2.3
1967	1	0.01	0.08	<0.01	0.2	0.01	0.12	6	6.3	<10	4.4	5.9
1967	5	<0.01	<0.01	<0.01	0.26	0.12	0.03	4	4.5	12	2.1	3.8
1967/68	1	0.01	0.09	<0.01	0.2	0.01	0.13	6	5.1	12	4.8	3.5
1967/68	5	<0.01	<0.01	<0.01	0.2	0.09	0.04	4	6.8	<10	2.4	6.4
1968	1	0.01	0.1	<0.01	0.22	0.01	0.12	6	6.2	<10	4.5	6.3
1968	5	<0.01	<0.01	<0.01	0.26	0.11	0.03	3	2.8	<10	2.8	6.9
1968/69	1	0.01	0.1	<0.01	0.19	0.01	0.14	7	16.2	12	4.7	14.1
1968/69	5	<0.01	<0.01	<0.01	0.21	0.08	0.04	4	3.3	13	3.2	6.1
1969	1	<0.01	0.06	<0.01	0.19	0.01	0.12	6	5.1	13	4.4	3.7
1969	5	<0.01	<0.01	<0.01	0.27	0.12	0.04	4	2.7	<10	3.4	5.2
1969/70	1	0.01	0.08	<0.01	0.18	0.01	0.13	6	4.6	11	4.5	4.2
1969/70	5	<0.01	<0.01	<0.01	0.16	0.08	0.05	4	3.5	17	2.9	3.7
1970	1	0.01	0.1	<0.01	0.19	0.01	0.14	6	7	12	4.5	6.1

Amphion stem (Stem 3) - Nutrient analyses results.

1970	5	<0.01	0.01	<0.01	0.28	0.13	0.04	4	8.3	12	3.5	35.3
1970/71	1	0.01	0.08	<0.01	0.16	0.01	0.14	6	7.8	22	4.7	7.2
1970/71	5	<0.01	0.01	0.01	0.23	0.11	0.04	4	3.8	22	3	8.7
1971	1	0.01	0.08	<0.01	0.17	0.01	0.13	6	6.1	<10	4.6	5.6
1971	5	<0.01	0.01	0.01	0.24	0.12	0.03	4	4.1	12	4.1	10.7
1971/72	1	0.01	0.11	<0.01	0.16	0.01	0.14	6	8.4	<10	4.7	5.6
1971/72	5	<0.01	0.01	<0.01	0.21	0.09	0.03	3	2.2	<10	3	3.1
1972	5	<0.01	0.01	<0.01	0.24	0.13	0.04	4	1.8	<10	5.9	2.4
1972	1	0.01	0.13	0.01	0.19	0.01	0.15	6	5.3	<10	4.7	2.9
1972/73	1	0.01	0.11	<0.01	0.19	0.01	0.14	6	4.3	<10	4.7	4.9
1972/73	5	<0.01	<0.01	<0.01	0.21	0.09	0.04	4	3.4	28	3.6	3.5
1973	1	0.01	0.12	0.01	0.18	0.01	0.15	6	14.8	20	5	8.8
1973	5	<0.01	0.01	<0.01	0.23	0.11	0.05	4	2.8	<10	2.7	6.9
1973/74	1	0.01	0.11	<0.01	0.17	0.01	0.17	7	5.6	<10	4.4	2
1973/74	5	<0.01	0.01	<0.01	0.21	0.08	0.04	4	3.6	<10	2.9	2.1
1974	1	0.01	0.16	0.01	0.2	0.01	0.16	6	4.4	<10	4.9	5.7
1974	5	<0.01	0.01	0.01	0.26	0.1	0.04	3	2.1	<10	3.5	1.3
1974/75	1	0.01	0.13	0.01	0.19	0.01	0.16	6	6	<10	4.7	2.5
1974/75	5	<0.01	0.01	<0.01	0.26	0.09	0.05	4	2.6	<10	2.9	1.4
1975	1	0.01	0.15	0.01	0.2	0.01	0.15	6	4.9	<10	4.5	3.6
1975	5	<0.01	0.01	0.01	0.27	0.09	0.04	4	2.2	<10	4.5	1.5
1975/76	1	0.01	0.13	0.01	0.18	0.01	0.15	6	8.4	<10	4.6	4.2
1975/76	5	<0.01	<0.01	<0.01	0.23	0.06	0.04	4	3.8	<10	2.7	4.1
1976	1	0.01	0.11	0.01	0.16	0.01	0.13	5	4	<10	4.7	1.4
1976	5	<0.01	0.01	0.01	0.27	0.08	0.04	4	4.9	13	12	3.3
1976/77	1	0.01	0.15	0.01	0.19	0.01	0.17	6	5.2	<10	4.4	15.3
1976/77	5	<0.01	<0.01	0.01	0.24	0.06	0.05	4	3	<10	8	1.8
1977	1	<0.01	0.06	0.01	0.19	0.03	0.1	5	3.3	15	6.2	1
1977/78	1	<0.01	0.09	0.01	0.15	0.01	0.11	5	4.4	<10	4.1	6.4
1977/78	5	<0.01	0.01	0.01	0.21	0.07	0.04	4	1.8	23	4	0.9
1978	1	0.01	0.15	0.01	0.17	0.01	0.15	5	13	<10	4.4	8.2
1978/79	1	0.01	0.16	0.01	0.16	0.01	0.17	6	4.1	8	4.7	1.8
1978/79	5	<0.01	<0.01	0.01	0.2	0.08	0.04	4	2.3	51	6.6	2.7
1979	1	0.01	0.18	0.01	0.15	0.01	0.16	5	4	<10	4.5	2.2
1979	5	<0.01	<0.01	0.01	0.19	0.09	0.04	4	1.6	9	5.6	0.9
1979/80	1	0.01	0.16	0.01	0.15	0.01	0.16	5	4	20	4.7	2.7

Gyngoorda stem (Stem 1) - Nitrogen analyses results
(1st cm section only)

Year	N
	% db
1930/31	0.2
1931	0.22
1931/32	0.26
1932	0.21
1932/33	0.21
1933	0.2
1933/34	0.18
1934	0.19
1934/35	0.24
1935	0.2
1935/36	0.23
1936	0.26
1936/37	0.26
1937	0.18
1937/38	0.2
1938	0.2
1938/39	0.25
1939	0.2
1939/40	0.22
1940	0.2
1977/78	0.39
1978	0.39
1978/79	0.39
1979	0.4
1979/80	0.41
1980	0.35
1980/81	0.41
1982	0.42
1982/83	0.42
1983	0.41
1983/84	0.39
1984	0.38
1984/85	0.39
1985	0.44
1985/86	0.39
1986	0.44
1986/87	0.47
1987	0.43
1987/88	0.44
1988	0.39

Appendix 6

Chapter 4 : Statistical Analyses Output

Minitab runs test output.

Stem 1 - 1st cm

Runs test

```
MTB > Runs 'K1' 'Ca1' 'Mg1' 'S1' 'B1' 'Cu1' 'Fe1' 'Mn1' 'Zn1' 'K5' 'Ca5'  &
CONT>     'Mg5' 'S5' 'B5' 'Cu5' 'Fe5' 'Mn5' 'Zn5'.

  K1

  K =    0.0356

  THE OBSERVED NO. OF RUNS =  26
  THE EXPECTED NO. OF RUNS =  79.2967
  57 OBSERVATIONS ABOVE K  125 BELOW
         THE TEST IS SIGNIFICANT AT  0.0000

  Ca1

  K =    0.4980

  THE OBSERVED NO. OF RUNS =  69
  THE EXPECTED NO. OF RUNS =  91.9560
  93 OBSERVATIONS ABOVE K   89 BELOW
         THE TEST IS SIGNIFICANT AT  0.0007

  Mg1

  K =    0.0804

  THE OBSERVED NO. OF RUNS =  43
  THE EXPECTED NO. OF RUNS =  89.5275
  76 OBSERVATIONS ABOVE K  106 BELOW
         THE TEST IS SIGNIFICANT AT  0.0000

  S1

  K =    0.0468

  THE OBSERVED NO. OF RUNS =  48
  THE EXPECTED NO. OF RUNS =  91.8242
  87 OBSERVATIONS ABOVE K   95 BELOW
         THE TEST IS SIGNIFICANT AT  0.0000

  B1

  K =    5.2418
```

```
THE OBSERVED NO. OF RUNS =  52
THE EXPECTED NO. OF RUNS =  84.5714
65 OBSERVATIONS ABOVE K  117 BELOW
      THE TEST IS SIGNIFICANT AT  0.0000
```

Cu1

```
K =    3.0824

THE OBSERVED NO. OF RUNS =  63
THE EXPECTED NO. OF RUNS =  82.7582
62 OBSERVATIONS ABOVE K  120 BELOW
      THE TEST IS SIGNIFICANT AT  0.0011
```

Fe1

```
K =    15.7747

THE OBSERVED NO. OF RUNS =  65
THE EXPECTED NO. OF RUNS =  78.5385
56 OBSERVATIONS ABOVE K  126 BELOW
      THE TEST IS SIGNIFICANT AT  0.0183
```

Mn1

```
K =    4.7429

THE OBSERVED NO. OF RUNS =  66
THE EXPECTED NO. OF RUNS =  89.1868
75 OBSERVATIONS ABOVE K  107 BELOW
      THE TEST IS SIGNIFICANT AT  0.0004
```

Zn1

```
K =    16.9736

THE OBSERVED NO. OF RUNS =  59
THE EXPECTED NO. OF RUNS =  88.0330
72 OBSERVATIONS ABOVE K  110 BELOW
      THE TEST IS SIGNIFICANT AT  0.0000
```

N1

```
K =    0.2155

THE OBSERVED NO. OF RUNS =  11
THE EXPECTED NO. OF RUNS =  10.6000
8 OBSERVATIONS ABOVE K   12 BELOW
      THE TEST IS SIGNIFICANT AT  0.8479
      CANNOT REJECT AT ALPHA = 0.05
```

N2

```
 K =    0.4075

 THE OBSERVED NO. OF RUNS =  9
 THE EXPECTED NO. OF RUNS =  11.0000
 10 OBSERVATIONS ABOVE K   10 BELOW
* N SMALL--FOLLOWING APPROX. MAY BE INVALID
        THE TEST IS SIGNIFICANT AT  0.3583
        CANNOT REJECT AT ALPHA = 0.05
```

<u>**Stem 1 - 5th cm**</u>

Runs test

K5

```
 K =    0.0445

 THE OBSERVED NO. OF RUNS =  16
 THE EXPECTED NO. OF RUNS =  66.6813
 43 OBSERVATIONS ABOVE K  139 BELOW
        THE TEST IS SIGNIFICANT AT  0.0000
```

Ca5

```
 K =    0.1225

 THE OBSERVED NO. OF RUNS =  86
 THE EXPECTED NO. OF RUNS =  91.1099
 82 OBSERVATIONS ABOVE K  100 BELOW
        THE TEST IS SIGNIFICANT AT  0.4432
        CANNOT REJECT AT ALPHA = 0.05
```

Mg5

```
 K =    0.1705

 THE OBSERVED NO. OF RUNS =  40
 THE EXPECTED NO. OF RUNS =  91.7253
 86 OBSERVATIONS ABOVE K   96 BELOW
        THE TEST IS SIGNIFICANT AT  0.0000
```

S5

```
 K =    0.0234

 THE OBSERVED NO. OF RUNS =  57
```

```
THE EXPECTED NO. OF RUNS =  81.4396
60 OBSERVATIONS ABOVE K  122 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

B5

```
K =    4.1703

THE OBSERVED NO. OF RUNS =  45
THE EXPECTED NO. OF RUNS =  81.4396
60 OBSERVATIONS ABOVE K  122 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Cu5

```
K =    1.4275

THE OBSERVED NO. OF RUNS =  82
THE EXPECTED NO. OF RUNS =  88.4396
73 OBSERVATIONS ABOVE K  109 BELOW
       THE TEST IS SIGNIFICANT AT  0.3192
       CANNOT REJECT AT ALPHA = 0.05
```

Fe5

```
K =   31.5879

THE OBSERVED NO. OF RUNS =  43
THE EXPECTED NO. OF RUNS =  49.7582
29 OBSERVATIONS ABOVE K  153 BELOW
       THE TEST IS SIGNIFICANT AT  0.0598
       CANNOT REJECT AT ALPHA = 0.05
```

Mn5

```
K =    4.2066

THE OBSERVED NO. OF RUNS =  55
THE EXPECTED NO. OF RUNS =  88.4396
73 OBSERVATIONS ABOVE K  109 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Zn5

```
K =   16.8527

THE OBSERVED NO. OF RUNS =  54
THE EXPECTED NO. OF RUNS =  85.6703
67 OBSERVATIONS ABOVE K  115 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Stem 2 - 1st cm

Runs test

K

```
K =    0.0291

THE OBSERVED NO. OF RUNS =  6
THE EXPECTED NO. OF RUNS =  16.2727
21 OBSERVATIONS ABOVE K   12 BELOW
      THE TEST IS SIGNIFICANT AT  0.0001
```

Ca

```
K =    0.2727

THE OBSERVED NO. OF RUNS =  61
THE EXPECTED NO. OF RUNS =  51.9216
49 OBSERVATIONS ABOVE K   53 BELOW
      THE TEST IS SIGNIFICANT AT  0.0707
      CANNOT REJECT AT ALPHA = 0.05
```

Mg

```
K =    0.1626

THE OBSERVED NO. OF RUNS =  30
THE EXPECTED NO. OF RUNS =  51.2941
45 OBSERVATIONS ABOVE K   57 BELOW
      THE TEST IS SIGNIFICANT AT  0.0000
```

S

```
K =    0.0465

THE OBSERVED NO. OF RUNS =  24
THE EXPECTED NO. OF RUNS =  51.0392
58 OBSERVATIONS ABOVE K   44 BELOW
      THE TEST IS SIGNIFICANT AT  0.0000
```

B

```
K =    5.8725

THE OBSERVED NO. OF RUNS =  20
THE EXPECTED NO. OF RUNS =  25.1569
88 OBSERVATIONS ABOVE K   14 BELOW
      THE TEST IS SIGNIFICANT AT  0.0287
```

Cu

```
K =    3.2363

THE OBSERVED NO. OF RUNS =  43
THE EXPECTED NO. OF RUNS =  44.1569
31 OBSERVATIONS ABOVE K   71 BELOW
       THE TEST IS SIGNIFICANT AT  0.7852
       CANNOT REJECT AT ALPHA = 0.05
```

Fe

```
K =   10.6176

THE OBSERVED NO. OF RUNS =  32
THE EXPECTED NO. OF RUNS =  35.5098
22 OBSERVATIONS ABOVE K   80 BELOW
       THE TEST IS SIGNIFICANT AT  0.2999
       CANNOT REJECT AT ALPHA = 0.05
```

Mn

```
K =    5.9833

THE OBSERVED NO. OF RUNS =  37
THE EXPECTED NO. OF RUNS =  51.8235
48 OBSERVATIONS ABOVE K   54 BELOW
       THE TEST IS SIGNIFICANT AT  0.0031
```

Zn

```
K =    6.6647

THE OBSERVED NO. OF RUNS =  31
THE EXPECTED NO. OF RUNS =  49.1765
39 OBSERVATIONS ABOVE K   63 BELOW
       THE TEST IS SIGNIFICANT AT  0.0001
```

Stem 2 - 5th cm

Runs test

K

```
K =    0.0115

THE OBSERVED NO. OF RUNS =   5
THE EXPECTED NO. OF RUNS =   6.1000
```

```
 3 OBSERVATIONS ABOVE K   17 BELOW
        THE TEST IS SIGNIFICANT AT  0.2946
        CANNOT REJECT AT ALPHA = 0.05
```

Ca

```
 K =     0.1174

 THE OBSERVED NO. OF RUNS =  41
 THE EXPECTED NO. OF RUNS =  52.0000
 51 OBSERVATIONS ABOVE K   51 BELOW
        THE TEST IS SIGNIFICANT AT  0.0288
```

Mg

```
 K =     0.2664

 THE OBSERVED NO. OF RUNS =  46
 THE EXPECTED NO. OF RUNS =  51.5098
 46 OBSERVATIONS ABOVE K   56 BELOW
        THE TEST IS SIGNIFICANT AT  0.2684
        CANNOT REJECT AT ALPHA = 0.05
```

S

```
 K =     0.0319

 THE OBSERVED NO. OF RUNS =  29
 THE EXPECTED NO. OF RUNS =  38.7451
 25 OBSERVATIONS ABOVE K   77 BELOW
        THE TEST IS SIGNIFICANT AT  0.0087
```

B

```
 K =     4.1176

 THE OBSERVED NO. OF RUNS =  20
 THE EXPECTED NO. OF RUNS =  30.6471
 18 OBSERVATIONS ABOVE K   84 BELOW
        THE TEST IS SIGNIFICANT AT  0.0003
```

Cu

```
 K =     1.3559

 THE OBSERVED NO. OF RUNS =  63
 THE EXPECTED NO. OF RUNS =  51.9216
 49 OBSERVATIONS ABOVE K   53 BELOW
        THE TEST IS SIGNIFICANT AT  0.0275
```

Fe

```
K =    13.1373

THE OBSERVED NO. OF RUNS =  40
THE EXPECTED NO. OF RUNS =  41.6275
28 OBSERVATIONS ABOVE K   74 BELOW
       THE TEST IS SIGNIFICANT AT  0.6836
       CANNOT REJECT AT ALPHA = 0.05
```

Mn

```
K =    6.7275

THE OBSERVED NO. OF RUNS =  30
THE EXPECTED NO. OF RUNS =  46.9804
35 OBSERVATIONS ABOVE K   67 BELOW
       THE TEST IS SIGNIFICANT AT  0.0002
```

Zn

```
K =    8.4804

THE OBSERVED NO. OF RUNS =  43
THE EXPECTED NO. OF RUNS =  49.6275
40 OBSERVATIONS ABOVE K   62 BELOW
       THE TEST IS SIGNIFICANT AT  0.1667
       CANNOT REJECT AT ALPHA = 0.05
```

Stem 3 - 1st cm

Runs test

```
MTB > Runs 'K' 'Ca' 'Mg' 'S' 'B' 'Cu' 'Fe' 'Mn' 'Zn'.
```

K

```
K =    0.0990

THE OBSERVED NO. OF RUNS =  32
THE EXPECTED NO. OF RUNS =  49.9796
48 OBSERVATIONS ABOVE K   50 BELOW
       THE TEST IS SIGNIFICANT AT  0.0003
```

Ca

```
K =    0.1619

THE OBSERVED NO. OF RUNS =  33
THE EXPECTED NO. OF RUNS =  49.4898
44 OBSERVATIONS ABOVE K   54 BELOW
```

```
        THE TEST IS SIGNIFICANT AT  0.0007
```

Mg

```
K =    0.0112

THE OBSERVED NO. OF RUNS =  15
THE EXPECTED NO. OF RUNS =  20.5306
11 OBSERVATIONS ABOVE K   87 BELOW
        THE TEST IS SIGNIFICANT AT  0.0043
```

S

```
K =    0.1010

THE OBSERVED NO. OF RUNS =  12
THE EXPECTED NO. OF RUNS =  48.6939
41 OBSERVATIONS ABOVE K   57 BELOW
        THE TEST IS SIGNIFICANT AT  0.0000
```

B

```
K =    5.3061

THE OBSERVED NO. OF RUNS =  27
THE EXPECTED NO. OF RUNS =  49.6735
45 OBSERVATIONS ABOVE K   53 BELOW
        THE TEST IS SIGNIFICANT AT  0.0000
```

Cu

```
K =    5.7418

THE OBSERVED NO. OF RUNS =  37
THE EXPECTED NO. OF RUNS =  40.1224
27 OBSERVATIONS ABOVE K   71 BELOW
        THE TEST IS SIGNIFICANT AT  0.4260
        CANNOT REJECT AT ALPHA = 0.05
```

Fe

```
K =   12.9082

THE OBSERVED NO. OF RUNS =  19
THE EXPECTED NO. OF RUNS =  37.2449
24 OBSERVATIONS ABOVE K   74 BELOW
        THE TEST IS SIGNIFICANT AT  0.0000
```

Mn

```
K =    4.4878

THE OBSERVED NO. OF RUNS =  38
THE EXPECTED NO. OF RUNS =  49.9184
47 OBSERVATIONS ABOVE K   51 BELOW
       THE TEST IS SIGNIFICANT AT  0.0155
```

Zn

```
K =    5.9071

THE OBSERVED NO. OF RUNS =  28
THE EXPECTED NO. OF RUNS =  49.0000
42 OBSERVATIONS ABOVE K   56 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Stem 3 - 5th cm

```
MTB > Runs 'Ca' 'Mg' 'S' 'B' 'Cu' 'Fe' 'Mn' 'Zn'.
```

Ca

```
K =    0.2380

THE OBSERVED NO. OF RUNS =  60
THE EXPECTED NO. OF RUNS =  46.9783
45 OBSERVATIONS ABOVE K   47 BELOW
       THE TEST IS SIGNIFICANT AT  0.0064
```

Mg

```
K =    0.1382

THE OBSERVED NO. OF RUNS =  39
THE EXPECTED NO. OF RUNS =  46.9783
45 OBSERVATIONS ABOVE K   47 BELOW
       THE TEST IS SIGNIFICANT AT  0.0945
       CANNOT REJECT AT ALPHA = 0.05
```

S

```
K =    0.0318

THE OBSERVED NO. OF RUNS =  20
THE EXPECTED NO. OF RUNS =  37.4130
25 OBSERVATIONS ABOVE K   67 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

B

```
K =    3.5761

THE OBSERVED NO. OF RUNS =  33
THE EXPECTED NO. OF RUNS =  45.6087
54 OBSERVATIONS ABOVE K   38 BELOW
       THE TEST IS SIGNIFICANT AT  0.0065
```

Cu

```
K =    2.8543

THE OBSERVED NO. OF RUNS =  44
THE EXPECTED NO. OF RUNS =  41.4348
30 OBSERVATIONS ABOVE K   62 BELOW
       THE TEST IS SIGNIFICANT AT  0.5401
       CANNOT REJECT AT ALPHA = 0.05
```

Fe

```
K =   34.6087

THE OBSERVED NO. OF RUNS =  14
THE EXPECTED NO. OF RUNS =  38.3043
26 OBSERVATIONS ABOVE K   66 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Mn

```
K =    5.0000

THE OBSERVED NO. OF RUNS =  25
THE EXPECTED NO. OF RUNS =  43.8696
34 OBSERVATIONS ABOVE K   58 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Zn

```
K =    6.3065

THE OBSERVED NO. OF RUNS =  25
THE EXPECTED NO. OF RUNS =  43.3261
33 OBSERVATIONS ABOVE K   59 BELOW
       THE TEST IS SIGNIFICANT AT  0.0000
```

Stem 1, 1st cm: Two-way analysis of variance output. Comparing mean nutrient concentrations in relation to fire and season, and the interaction between the two.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.001	.001	.002	.9685
Years since fire	5	1.174	.235	.452	.8109
Sum/Win * Year...	5	6.403	1.281	2.469	.0355
Residual	138	71.578	.519		

Dependent: lnK

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	4.176E-4	4.176E-4	.068	.7944
Years since fire	5	.153	.031	4.991	.0003
Sum/Win * Year...	5	.084	.017	2.748	.0211
Residual	144	.882	.006		

Dependent: Ca

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	6.352E-6	6.352E-6	.013	.9086
Years since fire	5	.020	.004	8.530	.0001
Sum/Win * Year...	5	.021	.004	8.812	.0001
Residual	144	.069	4.799E-4		

Dependent: Mg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	3.027E-4	3.027E-4	.005	.9425
Years since fire	5	.071	.014	.244	.9421
Sum/Win * Year...	5	.155	.031	.534	.7505
Residual	144	8.343	.058		

Dependent: lnS

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.012	.012	.015	.9026
Years since fire	5	6.922	1.384	1.739	.1293
Sum/Win * Year...	5	8.000	1.600	2.010	.0806
Residual	144	114.629	.796		

Dependent: B

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.101	.101	.434	.5112
Years since fire	5	.794	.159	.679	.6401
Sum/Win * Year...	5	2.139	.428	1.830	.1106
Residual	144	33.667	.234		

Dependent: SineCu

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.047	.047	.073	.7874
Years since fire	5	.862	.172	.270	.9286
Sum/Win * Year...	5	2.376	.475	.745	.5913
Residual	129	82.310	.638		

Dependent: lnFe

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.150	.150	.313	.5770
Years since fire	5	17.335	3.467	7.243	.0001
Sum/Win * Year...	5	5.987	1.197	2.501	.0332
Residual	144	68.927	.479		

Dependent: Mn

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.018	.018	.063	.8025
Years since fire	5	3.974	.795	2.716	.0224
Sum/Win * Year...	5	5.215	1.043	3.565	.0045
Residual	144	42.136	.293		

Dependent: lnZn

Stem 1, 5th cm: Two-way analysis of variance output. Comparing mean nutrient concentrations in relation to fire and season, and the interaction between the two.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.438	.438	.776	.3799
Years since fire	5	2.315	.463	.820	.5375
Summer/Winter...	5	6.124	1.225	2.168	.0609
Residual	142	80.213	.565		

Dependent: lnK

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.016	.016	33.131	.0001
Years since fire	5	.004	.001	1.769	.1228
Summer/Winter...	5	.002	4.737E-4	.976	.4347
Residual	144	.070	4.854E-4		

Dependent: Ca

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.005	.005	2.369	.1260
Years since fire	5	.068	.014	6.481	.0001
Summer/Winter...	5	.018	.004	1.745	.1280
Residual	144	.302	.002		

Dependent: Mg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.031	.031	.786	.3767
Years since fire	5	.785	.157	4.012	.0019
Summer/Winter...	5	.252	.050	1.289	.2718
Residual	144	5.634	.039		

Dependent: lnS

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	11.404	11.404	8.085	.0051
Years since fire	5	15.939	3.188	2.260	.0516
Summer/Winter...	5	16.946	3.389	2.403	.0398
Residual	144	203.115	1.411		

Dependent: B

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.064	.064	1.114	.2931
Years since fire	5	1.123	.225	3.883	.0025
Summer/Winter...	5	.733	.147	2.532	.0314
Residual	144	8.332	.058		

Dependent: neg1onCu

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	3.437E-4	3.437E-4	.167	.6837
Years since fire	5	.011	.002	1.059	.3863
Summer/Winter...	5	.009	.002	.894	.4871
Residual	134	.276	.002		

Dependent: neg1onFe

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.319	.319	2.408	.1229
Years since fire	5	1.067	.213	1.612	.1604
Summer/Winter...	5	.223	.045	.336	.8902
Residual	144	19.062	.132		

Dependent: lnMn

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Summer/Winter	1	.737	.737	2.079	.1515
Years since fire	5	4.366	.873	2.463	.0356
Summer/Winter...	5	6.651	1.330	3.753	.0032
Residual	144	51.046	.354		

Dependent: lnZn

Stem 2, 1st cm: Two-way analysis of variance output. Comparing mean nutrient concentrations in relation to fire and season, and the interaction between the two.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	3.140E-6	3.140E-6	.130	.7200
Years since fire	5	1.631E-4	3.262E-5	1.354	.2619
Sum/Wint * Yea...	5	8.386E-5	1.677E-5	.696	.6293
Residual	40	.001	2.408E-5		

Dependent: K

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	.015	.015	26.244	.0001
Years since fire	5	.020	.004	7.306	.0001
Sum/Wint * Yea...	5	.008	.002	2.874	.0255
Residual	42	.023	.001		

Dependent: Ca

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	1.408E-4	1.408E-4	.244	.6239
Years since fire	5	.012	.002	4.068	.0042
Sum/Wint * Yea...	5	.001	1.344E-4	.233	.9460
Residual	42	.024	.001		

Dependent: Mg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	5.926E-6	5.926E-6	.153	.6980
Years since fire	5	1.781E-4	3.563E-5	.918	.4787
Sum/Wint * Yea...	5	1.326E-4	2.652E-5	.683	.6386
Residual	42	.002	3.881E-5		

Dependent: S

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	.033	.033	.179	.6740
Years since fire	5	1.693	.339	1.823	.1292
Sum/Wint * Yea...	5	.581	.116	.626	.6806
Residual	42	7.800	.186		

Dependent: B

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	.019	.019	.535	.4687
Years since fire	5	.055	.011	.313	.9022
Sum/Wint * Yea...	5	.351	.070	2.009	.0970
Residual	42	1.469	.035		

Dependent: lnCu

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	.002	.002	.010	.9217
Years since fire	5	1.026	.205	.860	.5158
Sum/Wint * Yea...	5	1.351	.270	1.133	.3583
Residual	42	10.018	.239		

Dependent: lnFe

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	.054	.054	4.030	.0511
Years since fire	5	.256	.051	3.805	.0062
Sum/Wint * Yea...	5	.040	.008	.590	.7074
Residual	42	.566	.013		

Dependent: sqrootMn

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Wint	1	3.710	3.710	1.178	.2839
Years since fire	5	16.591	3.318	1.054	.3993
Sum/Wint * Yea...	5	14.933	2.987	.949	.4599
Residual	42	132.223	3.148		

Dependent: Zn

Stem 2, 5th cm: Two-way analysis of variance output. Comparing mean nutrient concentrations in relation to fire and season, and the interaction between the two.

K

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	7.042E-8	7.042E-8	.007	.9321
Years since fire	5	7.485E-5	1.497E-5	1.566	.1961
Sum/Win * Year...	5	5.141E-5	1.028E-5	1.076	.3911
Residual	34	3.250E-4	9.559E-6		

Dependent: K

Ca

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.004	.004	.084	.7734
Years since fire	5	.176	.035	.772	.5755
Sum/Win * Year...	5	.084	.017	.368	.8679
Residual	42	1.915	.046		

Dependent: lnCa

Mg

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.236	.236	7.197	.0104
Years since fire	5	.496	.099	3.025	.0202
Sum/Win * Year...	5	.052	.010	.316	.9007
Residual	42	1.379	.033		

Dependent: lnMg

S

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	3.704E-5	3.704E-5	.972	.3298
Years since fire	5	4.833E-5	9.667E-6	.254	.9356
Sum/Win * Year...	5	2.554E-4	5.107E-5	1.341	.2661
Residual	42	.002	3.810E-5		

Dependent: S

B

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.015	.015	.041	.8396
Years since fire	5	1.409	.282	.789	.5634
Sum/Win * Year...	5	.331	.066	.186	.9665
Residual	42	15.000	.357		

Dependent: B

Cu

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	.435	.435	30.639	.0001
Years since fire	5	.180	.036	2.533	.0431
Sum/Win * Year...	5	.066	.013	.928	.4726
Residual	42	.596	.014		

Dependent: neg1onCu

Fe

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	114.726	114.726	5.077	.0295
Years since fire	5	23.933	4.787	.212	.9556
Sum/Win * Year...	5	49.437	9.887	.438	.8197
Residual	42	949.000	22.595		

Dependent: Fe

Mn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	1.539	1.539	9.227	.0041
Years since fire	5	.119	.024	.143	.9811
Sum/Win * Year...	5	.597	.119	.716	.6147
Residual	42	7.004	.167		

Dependent: lnMn

Zn

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sum/Win	1	4.434	4.434	.396	.5326
Years since fire	5	42.467	8.493	.758	.5849
Sum/Win * Year...	5	33.334	6.667	.595	.7036
Residual	42	470.391	11.200		

Dependent: Zn

Stem 3, 1st cm seasonal comparison
t-tests for Paired Samples

```
                     Number of              2-tail
Variable               pairs        Corr    Sig          Mean           SD     SE of Mean
-------------------------------------------------------------------------------------------
B_SUM      B sum                                       5.4286         .791           .113
                        49          .668    .000
B_WIN      B win                                       5.1837         .834           .119
-------------------------------------------------------------------------------------------


         Paired Differences           |
  Mean           SD     SE of Mean    |      t-value             df       2-tail Sig
--------------------------------------|----------------------------------------------------
  .2449         .662          .095    |        2.59              48             .013
95% CI (.055, .435)                   |


                     Number of              2-tail
Variable               pairs        Corr    Sig          Mean           SD     SE of Mean
-------------------------------------------------------------------------------------------
CA_SUM     Ca sum                                       .1578         .023           .003
                        49          .726    .000
CA_WIN     Ca win                                       .1661         .024           .003
-------------------------------------------------------------------------------------------


         Paired Differences           |
  Mean           SD     SE of Mean    |      t-value             df       2-tail Sig
--------------------------------------|----------------------------------------------------
 -.0084         .018          .003    |       -3.33              48             .002
95% CI (-.013, -.003)                 |


                     Number of              2-tail
Variable               pairs        Corr    Sig          Mean           SD     SE of Mean
-------------------------------------------------------------------------------------------
CU_SUM     Cu sum                                      5.8367        3.624           .518
                        49          .028    .850
CU_WIN     Cu win                                      5.6469        4.118           .588
-------------------------------------------------------------------------------------------


         Paired Differences           |
  Mean           SD     SE of Mean    |      t-value             df       2-tail Sig
--------------------------------------|----------------------------------------------------
  .1898        5.409          .773    |         .25              48             .807
95% CI (-1.364, 1.744)                |
```

```
t-tests for Paired Samples


                      Number of             2-tail
Variable                pairs      Corr     Sig          Mean           SD     SE of Mean
------------------------------------------------------------------------------------------
FE_SUM     Fe sum                                     15.8182        3.027           .913
                         11        -.019     .956
FE_WIN     Fe win                                     15.8182        4.119          1.242
------------------------------------------------------------------------------------------


              Paired Differences          |
     Mean            SD       SE of Mean  |      t-value              df      2-tail Sig
------------------------------------------|-----------------------------------------------
     .0000          5.158          1.555  |        .00                10           1.000
95% CI (-3.465, 3.465)                    |


                      Number of             2-tail
Variable                pairs      Corr     Sig          Mean           SD     SE of Mean
------------------------------------------------------------------------------------------
K_SUM    K sum                                          .1086         .045           .006
                         49         .531    .000
K_WIN    K win                                          .0894         .032           .005
------------------------------------------------------------------------------------------


              Paired Differences          |
     Mean            SD       SE of Mean  |      t-value              df      2-tail Sig
------------------------------------------|-----------------------------------------------
     .0192           .039           .006  |       3.47                48            .001
95% CI (.008, .030)                       |


                      Number of             2-tail
Variable                pairs      Corr     Sig          Mean           SD     SE of Mean
------------------------------------------------------------------------------------------
MG_SUM    Mg sum                                        .0108         .003           .000
                         49         .061    .675
MG_WIN    Mg win                                        .0116         .004           .001
------------------------------------------------------------------------------------------


              Paired Differences          |
     Mean            SD       SE of Mean  |      t-value              df      2-tail Sig
------------------------------------------|-----------------------------------------------
    -.0008           .005           .001  |      -1.16                48            .252
95% CI (-.002, .001)                      |
```

```
t-tests for Paired Samples

                       Number of             2-tail
Variable                 pairs        Corr   Sig          Mean          SD    SE of Mean
-----------------------------------------------------------------------------------------
MN_SUM     Mn sum                                       4.4510        .200          .029
                          49         -.036    .806
MN_WIN     Mn win                                       4.5245        .322          .046
-----------------------------------------------------------------------------------------


         Paired Differences          |
   Mean            SD     SE of Mean |        t-value            df     2-tail Sig
-------------------------------------|-------------------------------------------------
 -.0735          .385           .055 |         -1.34             48           .188
95% CI (-.184, .037)                 |


                       Number of             2-tail
Variable                 pairs        Corr   Sig          Mean          SD    SE of Mean
-----------------------------------------------------------------------------------------
S_SUM     S sum                                          .1031        .034          .005
                          49          .942    .000
S_WIN     S win                                          .0990        .031          .004
-----------------------------------------------------------------------------------------


         Paired Differences          |
   Mean            SD     SE of Mean |        t-value            df     2-tail Sig
-------------------------------------|-------------------------------------------------
  .0041          .012           .002 |          2.48             48           .017
95% CI (.001, .007)                  |


                       Number of             2-tail
Variable                 pairs        Corr   Sig          Mean          SD    SE of Mean
-----------------------------------------------------------------------------------------
ZN_SUM     Zn sum                                       5.7796       3.944          .563
                          49          .464    .001
ZN_WIN     Zn win                                       6.0347       4.828          .690
-----------------------------------------------------------------------------------------


         Paired Differences          |
   Mean            SD     SE of Mean |        t-value            df     2-tail Sig
-------------------------------------|-------------------------------------------------
 -.2551         4.606           .658 |          -.39             48           .700
95% CI (-1.578, 1.068)               |
```

```
Stem 3, 5th cm seasonal comparison
t-tests for Paired Samples

                     Number of              2-tail
 Variable              pairs        Corr    Sig          Mean           SD      SE of Mean
 -------------------------------------------------------------------------------------------
 B_SUM     B sum                                        3.5435         .546           .080
                         46         .395     .007
 B_WIN     B win                                        3.6087         .493           .073
 -------------------------------------------------------------------------------------------


              Paired Differences            |
    Mean               SD      SE of Mean    |         t-value          df        2-tail Sig
 --------------------------------------------|----------------------------------------------
  -.0652           .574             .085     |           -.77            45              .445
 95% CI (-.236, .105)                        |


                     Number of              2-tail
 Variable              pairs        Corr    Sig          Mean           SD      SE of Mean
 -------------------------------------------------------------------------------------------
 CA_SUM     Ca sum                                       .2176         .034           .005
                         46         .397     .006
 CA_WIN     Ca win                                       .2585         .028           .004
 -------------------------------------------------------------------------------------------


              Paired Differences            |
    Mean               SD      SE of Mean    |         t-value          df        2-tail Sig
 --------------------------------------------|----------------------------------------------
  -.0409           .035             .005     |          -8.00            45              .000
 95% CI (-.051, -.031)                       |


                     Number of              2-tail
 Variable              pairs        Corr    Sig          Mean           SD      SE of Mean
 -------------------------------------------------------------------------------------------
 CU_SUM     Cu sum                                      3.0087        1.784           .263
                         46         .081     .594
 CU_WIN     Cu win                                      2.7000        1.792           .264
 -------------------------------------------------------------------------------------------


              Paired Differences            |
    Mean               SD      SE of Mean    |         t-value          df        2-tail Sig
 --------------------------------------------|----------------------------------------------
   .3087          2.424             .357     |            .86            45              .392
 95% CI (-.411, 1.029)                       |
```

```
t-tests for Paired Samples


                     Number of             2-tail
Variable               pairs       Corr    Sig           Mean         SD       SE of Mean
-----------------------------------------------------------------------------------------

FE_SUM     Fe sum                                     49.2400     29.966            5.993
                        25         .190     .363
FE_WIN     Fe win                                     57.2400    106.332           21.266
-----------------------------------------------------------------------------------------


            Paired Differences               |
    Mean             SD       SE of Mean     |        t-value            df      2-tail Sig
---------------------------------------------|-------------------------------------------
-8.0000        104.857          20.971       |          -.38             24            .706
95% CI (-51.283, 35.283)                     |


                     Number of             2-tail
Variable               pairs       Corr    Sig           Mean         SD       SE of Mean
-----------------------------------------------------------------------------------------

K_SUM     K sum                                         .0100       .000             .000
                        22           .        .
K_WIN     K win                                         .0100       .000             .000
-----------------------------------------------------------------------------------------

>Warning # 11836.  Command name: T-TEST
>The standard error of the difference is 0.  This analysis cannot be
>performed.


                     Number of             2-tail
Variable               pairs       Corr    Sig           Mean         SD       SE of Mean
-----------------------------------------------------------------------------------------

MG_SUM     Mg sum                                       .1196       .028             .004
                        46         .607     .000
MG_WIN     Mg win                                       .1567       .040             .006
-----------------------------------------------------------------------------------------


            Paired Differences               |
    Mean             SD       SE of Mean     |        t-value            df      2-tail Sig
---------------------------------------------|-------------------------------------------
 -.0372           .032            .005       |         -7.94             45            .000
95% CI (-.047, -.028)                        |
```

```
t-tests for Paired Samples


                    Number of            2-tail
Variable              pairs       Corr   Sig          Mean           SD     SE of Mean
--------------------------------------------------------------------------------------
MN_SUM    Mn sum                                     4.3152        2.359          .348
                       46         .865    .000
MN_WIN    Mn win                                     5.6848        2.867          .423
--------------------------------------------------------------------------------------


          Paired Differences            |
   Mean             SD     SE of Mean   |       t-value            df      2-tail Sig
----------------------------------------|--------------------------------------------
-1.3696          1.443           .213   |         -6.44            45            .000
95% CI (-1.798, -.941)                  |


                    Number of            2-tail
Variable              pairs       Corr   Sig          Mean           SD     SE of Mean
--------------------------------------------------------------------------------------
S_SUM     S sum                                       .0337         .007          .001
                       46         .657    .000
S_WIN     S win                                       .0300         .007          .001
--------------------------------------------------------------------------------------


          Paired Differences            |
   Mean             SD     SE of Mean   |       t-value            df      2-tail Sig
----------------------------------------|--------------------------------------------
  .0037           .006           .001   |          4.38            45            .000
95% CI (.002, .005)                     |


                    Number of            2-tail
Variable              pairs       Corr   Sig          Mean           SD     SE of Mean
--------------------------------------------------------------------------------------
ZN_SUM    Zn sum                                     5.6804        4.576          .675
                       46         .357    .015
ZN_WIN    Zn win                                     6.9326        6.709          .989
--------------------------------------------------------------------------------------


          Paired Differences            |
   Mean             SD     SE of Mean   |       t-value            df      2-tail Sig
----------------------------------------|--------------------------------------------
-1.2522          6.633           .978   |         -1.28            45            .207
95% CI (-3.222, .718)                   |
```