AN INVESTIGATION OF THE EFFECT OF TIME OF PRUNING ON THE GROWTH AND FRUITING OF LEMONS [*Citrus limon* (L.) Burmann *f*.] cv. Eureka

by

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DECLARATION

I, Timothy Michael Pittaway, declare that this dissertation is the result of my own investigation except where the work of others is acknowledged.

Signed…………………………………………………

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ABSTRACT

Pruning has been used to reduce tree size, allow light penetration into trees, improve yield, improve fruit size and fruit quality, overcome alternate bearing, assist fruit harvest, and assist pest and disease control. The use of pruning has increased due to improving agricultural management techniques such as high planting densities, use of mechanical machinery in orchards and the need for effective pesticide and pathological chemical spray applications.

The main objective of this study was to obtain a practical means of manipulating lemon trees at the right time. Pruning at the correct time to cultivate productive trees that produce quality fruit would have financial benefits. Lemon fruit quality is dependent on market demand and involves a number of features such as fruit shelf life, rind thickness, fruit size, rind colour, and juice content.

The study was conducted on 'Eureka' lemon trees budded on C. *volkameriana* rootstock, bearing the fifth and sixth commercial crops in 1999 and 2000 respectively. Twelve monthly pruning treatments per year were conducted on one row of trees starting in December 1997 (site 1) and repeated in the second year on the adjacent row of the same orchard starting in December 1998 (site 2). Selective pruning heading cuts were applied below the intercalation on the intercalary units. Potential branch bearing units were tagged and assessed during the harvest and flowering periods.

Summer pruning between 16 to 19 months before the subsequent April/May harvest, resulted in the longest and most complex (intercalation sprouted per axil) vegetative response. The estimated crop value indicated that summer pruning treatments produced the highest income. This was ascribed not to differences in fruit size or quality, but to an increase in yield.

The industry’s trend is to prune citrus from post-harvest to the pre-bloom stage. Results from this study have provided a beneficial cultural practice to prune during the summer months and provides a practice to optimise farm production and profit margins.

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INTRODUCTION

South Africa ranks third in the world among citrus fresh fruit exporting countries (FAO, 2000). Of all citrus exports from South Africa, lemon production accounts for 6 percent of total citrus production (Veldman, Barry and Alexander, 1996). In South Africa over 80 000 tonnes of lemons were produced during the 1998/99 season, of which over 43 000 tonnes were exported (FAO, 2000). Within South Africa's lemon production areas, the Eastern and Western Cape are the major production areas exporting more than 64 percent of the lemons exported from South Africa (Outspan International, 1994).

The worldwide tendency towards overproduction of citrus has meant that more effective cultivation methods such as pruning, irrigation and fertilisation are required to attain the requirements of the markets. Market requirements for lemons are less critical than for other citrus fruits; maturity ratio is not required for lemons, only size, shape, colour and juice percentage are required (Van Wyk, 2000).

The cultural practice of pruning in citrus has been associated with an improvement in fruit quality and production. In many planting systems, lemon trees become crowded by the interlacing of branches from adjoining trees by the time they reach maturity, to the point where, if no pruning is done, relatively few fruit are produced inside the tree. Lemon trees that are not pruned tend to have higher harvest costs due to the growth of shoots making the trees tall, and harvesting becomes an expensive production operation. Also excessive crowding of trees makes pest control difficult due to dense orchard planting systems requiring higher pesticide application to attain optimum coverage.

Pruning is one of few practices that can optimise production levels, fruit size and aid in entomological and pathological management. Cook (1992) reported that an invigorating effect was observed after pruning Clementines; increased vegetative growth at the expense of flowering, and increased flower leafiness. Regulation of flowering and fruit set has long been a goal to increase floral intensity and fruit set, and ultimately to achieve optimal yield.

The lemon tree produces several crops each year (Krajewski, 1990). There are three main harvest periods; June/July, September/October and December/January. In South Africa, lemons are usually pruned after the June/July harvest so that fewer mature fruit are lost.

The cultural practice of pruning lemon trees results in regrowth of vegetative shoots, which later flower and become fruitful. The effects of time of pruning on vegetative regrowth, flowering response and to what extent this has an effect on fruit size, fruit shape, rind thickness and juice percentage in lemon trees has not been researched in South Africa. Lemon growers need to know when is the ideal time is to prune their trees so that trees do not waste energy producing fruits which will be removed by pruning before reaching maturity.

The objective of this study was to investigate the effects of pruning at different times to provide lemon producers with a practical means to manipulate trees to increase crop value and minimise production costs.

CHAPTER ONE

LITERATURE REVIEW

1.1 INTRODUCTION

Citrus fruit have been cultivated for over four millennia in nearly every country within the 40°N and 40°S latitudes. Citrus appears to have originated in the humid tropical regions of China, South East Asia, and the islands of Indonesia and the Philippines (Swingle and Reece, 1967). Extensive movement of the various types of citrus probably occurred within the general area of citrus origin from before recorded history. The lemon [*Citrus limon* (L.) Burmann *f.*] fruit is of unknown origin, and is possibly a hybrid between citron (*C. medica*) and lime (*C. latifolia)* creating an intermediate species (Chapot, 1975).

The most distinctive fruit characteristics of the lemon are that fruit have high acidity levels, are oval to elliptically shaped and have a highly fragrant rind. Lemons are also sensitive to cold and the bearing cycle ranges from one to four crops. The growth characteristics of the lemon tree are vigorousness, upright-spreading and open. Trees can reach an unmanageable size under favourable conditions if no size control management is applied. Flower structure consists of large clusters which form throughout the year. Individual flowers are large, and purple-tinged in the bud and on the lower surface of petals. Many flowers are staminate (sterile male) because of pistil abortion, the incidence of which varies greatly from bloom to bloom and season to season (Reuther, Webber and Batchelor, 1967).

'Eureka' lemon is of Californian origin and was selected from a group of seedlings in 1858 (Hodgson, 1967). 'Eureka' and 'Lisbon' are the two main lemon cultivars grown in South Africa, of which 'Eureka' is the most widely grown cultivar (Veldman *et al.,* 1996). Compared to 'Lisbon' lemon, 'Eureka' has a spreading growth habit, is more sparsely foliated and is a less vigorous grower.

Today, mature lemon orchards (ten years and older) in South Africa cover about 1450 hectares, almost 5 percent of the total citrus tree count (Standard Bank, 2000). Rough lemon rootstock and Volkameriana has also proved to be a suitable rootstock for lemons in South Africa (Burdette, 1992). The main picking season for ‘Eureka’ lemon is spread over four months (June to September). The market prices peak over the June/July period and decrease towards the September/October period due to the arrival of Southern American fruit onto the overseas markets. Market requirements for fruit diameter range from 48 to 75 mm (Van Wyk, 2000). The fruit is often produced in terminal clusters, making it more susceptible to scarring, wind blemish and sunburn which is often detrimental to appearance for the export markets. The fruit has a small neck that is often surrounded by a marked areole. Juice content is normally high (above 42 percent) due to fairly thin rind. Seed content varies from zero to three seeds per fruit in California (Hodgson, 1967), although higher seed numbers occur in South Africa.

World exports of fresh lemons and limes have remained relatively stable from the late 1970’s (961 000 tonnes annual average) to the late 1980’s (1 002 000 tonnes annual average). Argentina, California (U.S.A.), Spain, Italy, Turkey, Greece and Egypt produce significant quantities of lemons, primarily ‘Eureka’ and ‘Villafranca’ cultivars (FAO, 1989). The liberalisation of South Africa's citrus industry occurred after the removal of the export monopoly in 1997. The outcome of this was expansion, an increase in export earnings and the development of new markets. These developments have bolstered South Africa's competitiveness in the global market (FAO, 2000). The Japanese market demands elongated lemons rather than round fruit. The definition of an elongated fruit is one in which the ratio of the diameter (measured at the widest point on the equator of the fruit) to the length (measured from the tip of the style end to the base of the neck or adjacent to the button if there is no neck) is 1:1.25 or more (I. Moore, personal communication, April 22, 1997).

1.2 VEGETATIVE GROWTH AND FLOWERING IN CITRUS

1.2.1 Definition of terms

Definitions of botanical terminology are as follows. Unless otherwise stated, terms have been defined by Davenport (1990).

Apical bud: The growing point at the tip of the stem, which consists of actively dividing cells.

Stem node: That part of the plant where one or more leaves or flowers arise.

Stem axis: The angle between the leaf and the stem on which it is borne; normal position for lateral buds.

Stem: Normally aerial part of axis of vascular plants, bearing leaves and buds at definite positions (nodes) and reproductive structures (Abercrombie, Hickman and Johnson, 1978). It may extend basipetally through several previous, sequentially produced vegetative or mixed shoots (intercalary units), which are easily identified by various degrees of bark formation.

Intercalary unit: Situated between regions of permanent tissue, e.g. the length of vegetative growth occurring in each flush. The apical intercalary unit is the last or present flush.

Intercalation: The cluster of nodes with short internodal lengths located at the terminal end of each intercalary unit.

Flush: The simultaneous, co-ordinated development of many shoots on stems distributed throughout a tree.

Vegetative shoot: Any shoot which bears only leaves. Once such a shoot matures and becomes lignified, it forms the apical intercalary unit of a stem from which new shoots will most likely develop.

Sympodial growth:

A primary axis that develops from a series of short lateral branches and often has a zigzag or irregular form.

1.2.2 Bud formation

In citrus, like all evergreen fruit trees, differentiation of flower buds or vegetative buds does not take place until new growth starts in the spring or at the recommencement of growth. According to Abbott (1935) this usually occurs after favourable environmental conditions and/or after adequate accumulation of food reserves. As a result, the time of bud differentiation differs from year to year according to seasonal variation in weather.

Further floral bud stimulants are evident in the fact that citrus trees occasionally blossom during the summer or early autumn when forced into growth following a prolonged dry period, or after branches have been girdled for a sufficient time and later forced into growth (Lord and Eckard, 1987).

Flower formation is a multi-stage process of development, which starts with floral initiation, the basic change by which a meristematic apex becomes floral rather than vegetative. The rate of flower development from bud break to anthesis is unrelated to the flower position or flower type and is positively correlated with heat unit accumulation (Lovatt, Streeter, Minter, O'Connell, Flaherty, Freeman and Goodall, 1984). Experiments on girdling and defoliation showed that mature leaves might be needed for flower bud induction as they may contribute to active substances promoting flower formation (Furr, Cooper and Reece, 1947). However, evidence exists that leaves are not essential for a floral inductive response (Southwick and Davenport, 1986).

Bud age and location in the tree canopy have a definite influence on sprouting and flowering (Krajewski and Rabe, 1995a). These findings were determined by assessing the number of spring shoots produced per sprouting axillary site. The number of spring shoots are determined by internal factors connected with previous crop load and the extent of vegetative flushes prior to bud sprouting in spring (Goldschmidt and Monselise, 1972).

Growth in a citrus tree is sympodial, thus all shoots are determinate and a negative correlation exists between shoot length and flowering (Lord and Eckard, 1987). Thus the shorter the stem the more flowers it bears. Krajewski and Rabe (1995a) found that heading of stems significantly increased percentage of leaf axils that sprouted in spring.

The cultural practice of pruning of stems increases vegetative and floral responses. Pruning performed on growing or dormant stems removes apical dominance, releases buds from correlative inhibition, and changes tree form and construction (Mika, 1986). The correlative mechanism, not yet fully explained, regulates stem growth, branching, and branch angle formation. The most noticeable phenomenon is apical dominance. The degree of dominance is a function of genetic loci, environmental factors, physiological processes, and plant age. Apical dominance can mean a) complete or nearly complete control of lateral buds by the apex, b) dominance of one growing shoot over another, and c) the apex influence on the orientation of branches and leaves.

Thimann (1937) developed a hypothesis that auxin produced in the shoot apex inhibits the growth of axillary buds. Went (1939) suggested that apical dominance is the result of preferential transport of nutrients towards the growing apex. A model developed by Jankiwicz (1972) indicates that the very small original differences among the buds or young shoots are quickly augmented, thus leading to differentiation of long and short shoots. A bud having an initial advantage over other buds starts to develop a little faster and produces more auxin, which stimulates cambial activity, thereby enabling the bud to develop better vascular connections with the main axis.

Buds can monopolise the initial transport of nutrients and hormones from the roots, and the reserves of sugars stored in the main axis, thereby suppressing the growth of other shoots. Pruning will therefore change the dominance relationships. The removal of the shoot apex, will nullify the control it has over the outgrowth of lateral buds. This will then result in one or more of the lateral buds growing out.

An increase in bud break is one of the effects which occur under higher light intensities (Reuther, 1974), which will in turn result in an increase in a floral response and hence an increase in fruit production. Pruning should increase in the illumination needed for photomorphologenic effects (Cohen, Goell, Cohen and Ismajovitch, 1988).

The primary effect of pruning is reducing the total number of buds on the tree, and the primary response to pruning is that some of the remaining buds break. If pruning is done in winter, before bud break, some buds form flowering shoots. These tend to be "green", where new leaves are present among the flowers on the new shoots. Other buds do not flower, but develop as vegetative regrowth. This regrowth will flower later in the tree's life.

Therefore, buds have two types of responses: there is a localised response, in the vicinity of the cut, from buds released from apical dominance, and there is also a general sprouting response on branches through the canopy in response to the increased amount of light.

1.2.3 Phenology of flowering

A citrus tree produces between 17 000 and 200 000 flowers per year. Citrus trees undergo three periods of adjustment, which occur during the development of the fruit after pollination (Erickson and Brannaman, 1960). Citrus trees begin their major flowering flush in subtropical regions during the late winter months when the days are short. It is not clear whether flowering might be induced by short day lengths or whether these short photoperiods might influence the induction of flowers by low temperatures (Lovatt *et al*., 1984).

With flowering, comes recurring vegetative flushes throughout the year. The recurring flushes provide bearing sites which can produce flowers, and in lemons results in cropping several times a year. This is a characteristic which has important practical implications as fruit harvested during June to August in the are more valuable than those harvested during the winter months (Veldman *et al*., 1996).

Flower buds start to form about 4 months before flowering actually occurs. The flowers responsible for the winter lemon harvest (June/July) originate from the spring growth flush. The September/October fruit ordinate from flowers formed in April/May. The flowers responsible for the summer lemon harvest (December/January) originate from the growth flush that occurs in late summer or early autumn (Dakis, 1983).

Monselise (1947) suggested that for citrus flowering the cessation of root growth is an essential prerequisite. The cessation of root growth can be caused by low temperatures, water stress, weak rootstocks or confined roots (Coelho and Medina, 1994).

Flowering is a critical factor in the determination of crop yield. Without it, fruit formation is impossible. Fruit set in citrus species occurs only in a very low percentage (less than 1 to 2 percent) of the initially formed flowers, thus fruit set is normally the primary factor determining final yield (Bercerra and Guardiola, 1984).

Lovatt *et al.* (1984) found that most flowers occur on one year old bearing branches and Sauer (1951) found that flowering on older bearing branches is limited. Five basic types of reproductive growth occur on these bearing branches during flowering: (i) generative shoots bearing flowers only on the previous season's growth; (ii) mixed shoots bearing a few flowers and leaves; (iii) mixed shoots bearing several flowers and a few large leaves; (iv) mixed shoots bearing a few flowers and many leaves; and (v) vegetative shoots bearing leaves only. Shoots with a high leaf to flower ratio, such as those in category (iv), produce and hold the greatest percentage of fruit to maturity (Davies and Albrigo,1994).

Goldschmidt and Monselise (1972) found that the presence of gibberellin-like substances in citrus tissues prevent flower formation. Monselise, Goren, Costo and Simkhi (1969) found that flowering was almost completely prevented when gibberellin was applied when natural induction occurred. On the other hand, growth antagonists, and other growth regulators, when applied to lemon trees, enhanced flower formation (Monselise and Halevy, 1964)

Usually, citrus trees simply produce too many flowers. This has two consequences. Most of the flowering shoots are leafless and most are actually single-flowered. In oranges and mandarins, fruit set of this type is very low. The tree thus wastes energy by flowering in this way as nutrients are diverted to structures that fall off later. Should pruning be applied during flowering it would remove wood tending to produce weak blossom. If done in winter, before bud break, weak wood is removed before the tree has diverted its energy to produce a blossom. Pruning also leads to a more vegetative character of flowering. These leafier flowers (fewer in number due to the thinning effect of wood removal) exhibit higher fruit set and larger fruit size, and improve internal quality.

1.2.4 Flowering stages

Three major stages which precede anthesis have been identified in floral development; induction, evocation (differentiation) and initiation (Davies and Albrigo, 1994).

Induction: This stage involves the events directing the transition from vegetative growth to the production of flowers (Davenport, 1990) or when the flowering stimulus is beginning to operate (Ayalon and Monselise, 1960). Citrus is considered autoinductive, because there is no single stimulus for induction (Monselise, 1985). Primary inductive factors include cold and water stress; water being the primary stress in tropical climates and cold in sub tropical climates.

In Italy, water stress has been used as a practical means of inducing flowering. A similar treatment is also employed for the production of summer lemons in Egypt and to some extent, for the control of blossoming of oranges and mandarins in India. Elimination of irrigation during the early summer for a long enough period (30 to 45 days) produces a degree of leaf wilting (most of the leaves are partially rolled up from the wilt). Soon after wilting is reached, water and nitrogen fertilizer is applied to induce an off-season bloom (Maranto and Hake, 1983).

Evocation (differentiation): Evans (1971) defined the initial events at the shoot apex in response to the arrival of the photoperiodic stimulus, which commits the plant to the subsequent formation of floral primordial, as evocation. The resting bud undergoes microscopic bud break (bud scale loosening) during May and June in the southern hemisphere. This is followed by macroscopic bud break which occurs in June and July, with flower buds becoming visible as early as August (Lord and Eckard, 1987).

Initiation: Flowering occurs after induction and differentiation when favourable temperature and soil moisture conditions prevail. The minimum threshold temperature for flowering is 9.4°C (Lovatt *et al.*, 1984). Terminal flower initiation occurs when there is a noticeable swelling of the axillary buds (Lord and Eckard, 1987). The terminal flower bud is last to open, probably due to apical dominance. In lemons, two main stages of differentiation were noted; an initial induction period that produced flower differentiation up to the production of sepals, and a subsequent rapid continuation of development, related to pedicel growth (Nir, Goren and Leshan, 1972).

1.2.5 Effects of temperature

Vegetative growth rate and fruit quality is strongly correlated to heat unit (H.U.) accumulation provided that shortages of water and nutrients are not limiting. The method of calculating H.U. is to sum the difference between the mean monthly temperature and the base temperature of 12.5°C (55°F) over a selected period, i.e. H.U. = (mean monthly temperature – 12.5°C) x days/month (Mendel, 1969). Maximum shoot growth occurs when temperatures reach between about 25°C and 31°C and growth is slower at about 32°C to 33°C (Girtron, 1927).

In subtropical climates, shoots produced during the warm summer months normally differ from those produced in the cooler spring months following the dormant period. Summer flush shoots are normally longer and thicker with larger leaves and longer internodes than spring flush shoots (Mendel, 1969). Studies by Lenz (1969) on ‘Washington Navel’ orange, found that no flowering occurred when placed under 30°C/25°C day/night regime, during a period of 11 months.

Low temperatures are promotive, although no investigations examined the threshold temperatures necessary to induce flowering (Davenport, 1990). The floral phenology of the lemon appears to be more noticeably influenced by climatic factors than other major citrus species. Manipulating trees through pruning prior to production of summer flushes may provide the ideal branch bearing units. This would provide units that are longer, thicker and have larger leaves.

In California, lemons which are grown in cool coastal areas with mild winters bloom throughout the year, while those grown in the dry desert with hot summers and cold winters, bloom mainly in spring. Thus bloom habit appears to be largely controlled by distinctive seasonal and diurnal temperature (Reuther, 1974).

1.3 FRUIT SET

1.3.1 Initial fruit set

There are two other factors besides flowering which determine final yield: (i) the percentage of fruit set, and (ii) the size ultimately reached by the fruits. Each of these factors is subject to complex regulation involving hormonal and nutritional aspects and the three corresponding developmental stages (induction, evocation and initiation) are interrelated, either directly or through their influence on the general status of the tree (Garcia-Luis, Fornes, Sanz and Guardiola, 1988).

In a study of the relationships between flowers and fruits of lemon, Reed and Halma (1919) determined that of 4440 lemon flower buds, 52 percent set fruit, 21 percent of these fruits attained a diameter of 7.5 mm, and only 7 percent reached full maturity. The primary cause controlling the dropping of flowers and young fruit is a weakening of tissue in a preformed abscission zone at the point of attachment of the base of the ovary to the disk or of the pedicel to the twig (Erickson, 1968).

Other factors influencing fruit set are flower development (Luckwill 1974), pollination, temperature (Graslund and Hansen, 1975), and light intensity (Jackson and Palmer, 1980).

The time of anthesis is linked to the percentage of initial fruit set. Flowers opening early in the bloom period have a much lower set than those opening late. Hormones have also been known to help with the capacity of fruit to persist during initial fruit set.

1.3.2 Fruit growth stages

Bain (1958) divided ‘Valencia’ orange fruit development into three stages: Stage one is a period of cell division, which occurs in the southern hemisphere in November and part of December. This period includes flowering and formation of various tissues in the small fruits. Respiration rate per unit mass of tissues is high in the flowers initially and then decreases during the first stage of growth.

Stage two follows the period of cell division and is characterised by the rapid enlargement of cells in the fruit. Although respiration rate per fruit rises rapidly during this stage of development, the respiration rate per unit mass of tissue continues to decline. Differentiation into the various tissue types such as juice sacs, albedo and flavedo occurs during this stage.

Stage three is regarded as the maturation period. Duration varies among cultivars, from 2 and 3 months for lemons and limes to more than 6 months for oranges and grapefruit. It is characterized by a reduced rate of growth and compositional changes associated with maturation. Changes in constituents are characterised mainly by increases in absolute amounts of soluble solids in the form of sugars and nitrogenous compounds to keep pace with additional fruit enlargement. Citric acid, however, continues to decrease in concentration, a change that begins during the second stage of fruit development.

Fruit size is a crucial factor in quality-conscious markets. Therefore when pruning is applied it should only remove wood of poor bearing potential. Competition among remaining fruits is thus lower, and these fruits grow rapidly. The new, healthy leaves produced photosynthesize actively, especially within the more “open” pruned canopy. Selective pruning seldom reduces yield significantly.

1.3.3 Effects of climate

Properties such as size and shape of the mature citrus fruit are determined at an early stage, within 2 months of flowering. Citrus fruit size increases during the night or early morning. A marked decrease in volume during the day is characteristic during sunny days. This is due to a faster rate of water loss by transpiration than of water uptake and transport to tissues. On very cloudy days citrus fruits may continue to increase in volume throughout the daylight hours, while under drought stress conditions, the tree may remove water from fruit to overcome stress, resulting in soft, spongy fruit.

At harvest time, fruit size is directly related to temperature, with the largest fruit being produced in the warmer regions. Sunny and warm conditions in spring are associated with larger than average fruit at harvest time. Hotter, drier inland areas produce mostly autumn and winter lemons, while cooler coastal climates are able to produce lemons throughout the year, with the heaviest sets in summer and autumn.

When the warmer and cooler climatic areas producing small and large fruit are compared, the differences in size are especially noticeable during October, November and January. It is evident that climatic factors can have a significant effect on yield and fruit size in citrus. Factors that are responsible for large fruit are detrimental to yield. High maximum temperatures in September, will increase fruit size, but will be detrimental to the yield of ‘Valencia’ oranges (Du Plessis, 1988). There is little information on the influence of high temperature on the set of lemons. Observations indicate that lemons are much less sensitive than ‘Navel’ oranges.

Good yields of lemons are obtained in the hottest citrus areas. Climate is the single most important factor influencing variations in fruit maturity and quality within a variety of lemon types. As in the case of the other varieties studied, lemons produced larger fruit in the warmer climatic zones. Lemons also tended to be slightly more elongated when grown in the warmer interior climatic zones. Lemon juice percentage increases from the coast to the interior (Nauer, Goodall, Summers and Reuther, 1975).

1.4 PRUNING CITRUS

1.4.1 The objective of pruning

Pruning of trees is a horticultural practice handed down from ancient times. The objective of pruning is to manipulate various aspects of vegetative and fruiting behaviour. One of the main pruning methods is selective pruning. Selective pruning means pruning at a certain time by removing certain types of unwanted branches and returning several months later to select and manage the resultant regrowth. Unpruned trees eventually assume a shape that is not ideal for commercial purposes.

As trees age, they increase in size and complexity with every growth flush. Eventually, they become no more than a core of tangled, dead wood. A major difference develops between the outside and inside of the canopy. Fruit size and quality decrease as bearing wood is forced ever outward and upwards. Orchards become inaccessible to tractors and spray equipment and therefore efficacy of pest control diminishes. Fruit is scarred by dead wood, and is difficult to harvest. The harvesting operation becomes expensive as ladders become indispensable to picking teams.

Citrus is a perennial evergreen that grows in two to five growth flushes per year. These flushes are potential bearing wood, and comprise new stems, leaves and axillary buds. Buds are induced to flower during winter. Flowering shoots emerge in spring from axillary buds borne on recently-produced growth flushes. No new shoots, whether vegetative or floral, can be produced if these buds do not sprout. The main effect of pruning is to reduce the number of buds.

The commercial practice in South Africa is to prune in winter, after harvest and once there is no danger of late frosts. By pruning in winter and before bud break, the trees have time to compensate for the removal of buds. The later the trees are pruned, the less time the trees have to make this adjustment.

The main complication of not pruning is the shading effect of the evergreen leaf canopy. Shaded buds seldom sprout. In addition, small twigs do not survive heavy shade: they die but persist in the canopy. These dead twigs scuff, scratch and puncture the fruit.

The main reason for pruning fruit trees is to foster a high quality yield (Lewis and McCarty, 1973). Other beneficial effects of pruning are control of tree form and size, improvement of canopy function, improvement of fruit size, ease of spraying and picking and improvement of packout.

Nowadays intensive planting of orchards is customary to maximise economic potential to achieve an earlier break-even point. This practice has resulted in a number of factors, which include the reduction in the availability of citrus land through urbanisation, the escalation of costs in the use of farm machinery, the availability of water for irrigation and labour. With this current trend towards higher planting densities and the need to control tree size in overcrowded orchards where shading of lower parts of the canopy is reducing yield, tree pruning has become an increasingly necessary and accepted practice (Cary, 1981).

1.4.2 Growth habit of a citrus tree

As trees grow together, lower limbs become shaded (less than 30 percent of full sunlight) and fruit production occurs primarily toward the outside and the top of the canopy of the tree (Davies and Albrigo, 1994).

This tendency is a result of the natural growth habit of the citrus tree. Most citrus varieties are upright in growth habit, although it varies with individual trees and varieties and under different environmental conditions.

The upright characteristic of citrus trees is most pronounced in the branches where dominance of the terminal growing portion is present (Reed and Halma, 1919). This results in low side-branch development. These vigorous shoots are called water sprouts or water shoots (Tucker, Wheaton and Muraro, 1994).

When the weight of fruit and leaves forces the branch into a horizontal position, apical dominance ceases and lateral buds along the upper side of the shoot begin to grow and the upright growth habit repeats itself (Halma, 1923). The natural sequence of events in the growth of citrus trees is a constant renewal of vertical growth, with consequent suppression and forcing downward of older growth.

1.4.3 Response to pruning

Shoot growth is most vigorous in the lemon, followed by the 'Valencia' orange, 'Navel' orange's, and grapefruit (Chandler, 1950). As already mentioned climatic differences have the greatest influence on vigour of shoot growth (Mendel, 1969).

According to Tucker *et al.* (1994), in the absence of deterring factors such as improper irrigation, disease, or ecological problems, the balance between growth and fruitfulness in the plant appears to be primarily dependent on a relationship between carbohydrates and nitrogen.

Kraus and Kraybill (1918) described the balance between growth and fruitfulness in relation to four general groups of plants: (i) plants exhibiting carbohydrate deficiency; (ii) plants with nitrogen starvation that are unable to grow or fruit normally; (iii) plants with a plentiful supply of nitrogen and high carbon assimilation that achieve moderate growth and bear heavy crops; and (iv) plants which have sufficient nitrogen available, but which manufacture carbohydrates in moderate amounts and produce vegetative growth at the expense of fruit production. The essential difference between the conditions appears to relate to the level and availability of carbohydrate reserves. This hypothesis still however does not explain the entire pruning responses observed in citrus trees (Lewis and McCarty, 1973).

The response of plants to grazing is similar to their response to pruning. There may be compensatory growth to replace the biomass removed and reproductive development may be affected via the direct effects of the removal of flowers and fruits and by alterations in reproductive physiology (Porter, 1989). Pruning healthy, mature trees usually reduces yield in proportion to the amount of foliage removed and can delay fruiting of young, nonbearing trees. Pruning should therefore be limited to that required for future canopy bearing surface development and for the conducting of efficient cultural and harvesting operations (Tucker *et al.,* 1994).

The orientation of branches in space has a marked effect on growth and fruiting. Shamel (1920) found that manipulation of the tree canopy through pruning had decreased the growth period of lemons to picking size. A decrease in vegetative growth rate and an increase in flowering were observed when branches were bent to a horizontal position. A possible explanation for this phenomenon is a change in the distribution of growth substances and carbohydrates. Favouring horizontal branches over upright ones should result in better growth control and more fruit production.

Iwagaki and Hirose (1977) found that pruning reduced the number of flowers and the total weight of new shoot growth, but increased the average length of new vegetative shoots. Although pruning clearly reduces the number of flowering sites in the pruned part of the canopy, a reduction in tree size and height through pruning enables more light to reach the lower, previously shaded part of the canopy, thus facilitating flower development and better fruit set in the unpruned part of the canopy. Little information concerning the optimum time for pruning of lemon trees is available.

Time of pruning may be restricted by the presence of mature fruit on the trees. Few problems occur with ‘Navel’ oranges and winter-harvest grapefruit, when the crop is harvested before spring. In coastal areas, lemons are usually pruned after the last main summer harvest so that fewer nearly mature fruit are lost. It seems logical to prune immediately after a crop has been harvested as trees do not waste their energy producing non-marketable fruit which are removed by pruning before reaching maturity.

1.4.4 Pruning method

Among the cultivation practices which impact on production costs of citrus fruits, pruning ranks second, after harvesting. It requires a large amount of labour which results in a considerable increase in farm expenses. Owing to the progressive shortage and growing cost of skilled labour, this important practice is performed at increasingly longer intervals (Giametta and Zimbalatti, 1983). Cost effective pruning methods are required to maximise income and reduce production expenses.

The main pruning methods for bearing lemon trees are listed below.

Formation pruning: This type of pruning is applied to the plants in the vegetative phase and is focused on establishing a good tree framework. This should be limited to the requirements for future tree development and for essential cultural practices.

Maintenance pruning: This is aimed at maintaining the vegetative balance of trees and obtaining the maximum yield, by removing excess foliage and improving light penetration.

Rejuvenation pruning: This is applied to old trees to improve their vigour and productivity.

Hedging: Consists of cutting the side of the tree back vertically. Hedging is required for the passage of equipment needed for orchard maintenance.

Topping: A heading-back type of pruning applied at the top of the tree and is important as it reduces harvesting costs.

Skirting: The removal of the lower part (skirt) of a tree. It facilitates the movement of orchard equipment, more efficient irrigation, allows broader coverage of herbicides and pest control.

Selective hand pruning: This method combines the prior mentioned pruning methods. Its primary focus is to control regrowth and response through precision pruning at the right position on the bearing branch. This has a definite positive influence on the blossom quality and allows a balance between fruiting and vegetative growth.

Mechanical and hand pruning are the two main methods used for pruning lemons. Pruning trees mechanically provides an option of different angles and intensities, at low labour cost. However it has been proven that this method results in unfavourable vegetative response on cut ends and in many cases causes dense regrowth. Hand pruning allows the pruner to have control of the type of cut to make, but compared with mechanical methods is labour intensive. Research has been conducted on the economic benefits of effective pruning methods on lemons (Boswell, Francis, Marvin and Colladay, 1975). The same authors found that annual hand pruning and topping gave a slightly higher yield and gross return, whereas the annual mechanical treatment was by far the least expensive.

Bevington and Bacon (1978) found the following on levels of severity of pruning: very light (1 year growth removed), light (2 year's growth removed), and moderate (3 year's growth removed). The results suggest that very light pruning may be carried out at any time of the year without adverse effects on yield. Removal of up to 2 year's growth in spring or early summer is also possible without affecting yield. Pruning moderately did not stimulate excessive vegetative regrowth and the regrowth is capable of setting fruit the year after pruning.

Heavier pruning stimulates excessive vegetative regrowth with relatively low fruitfulness. Krajewski (1994) found that severe heading treatments prior to bud break decreased yield the following year. Heading at bud swell increased sprouting and increased leaf to flower ratio.

Moderation is the keyword when pruning lemons, Blanchard (1930) showed that heavy pruning ‘Lisbon’ lemon trees over a 6 year period decreased yields by about 22 percent compared to lightly pruned trees. Severe pruning stimulates vigorous new vegetative growth, especially when done before a major growth flush. This happens because an undisturbed root system is providing water and nutrients to a reduced leaf area. The larger the wood that is cut, the larger the subsequent shoot. Severe pruning reduces fruiting and increases fruit size and juice content, and decreases soluble solids and acid (Tucker *et al.*, 1994). Koopmann (1896) found that the more severe the pruning the greater the development of longer and often more numerous shoots; in most cases, the average length of new shoots is greater than that of the shoots on unpruned trees. Furthermore the growth of shoots under severe pruning is faster and lasts longer in the growing season.

Skeletonisation pruning, involves the cutting back of the tree to the point where all branches smaller than approximately 2.5 cm in diameter are removed. Such pruning removes the entire vegetative shell of the tree. While immediate regrowth of skeletonized trees are healthy and vigorous, this vigour can continue; and it has been found that rejuvenation can fail in skeletonisation (McCarty and Lewis, 1964).

The effects of light or severe pruning were observed by Bevington and Bacon (1978) and Phillips (1978) who found that vegetative response showed no significant differences between treatments after the second and fourth year, respectively.

Lemon trees also produce strong lateral branches through the centre of the tree. Without pruning, the interior of the tree fills with tangled and crossing limbs. Such trees are difficult to harvest and pest control is a problem. Crowding also makes cultivation operations such as weed control and irrigation more difficult. A good framework of scaffold branches helps prevent limb breakage. Neglecting early selective pruning of lemon trees necessitates heavy cutting later on, which causes a delay and reduction in yield.

1.5 SUMMARY

Lemon prices have been relatively stable for the past 5 years and lemons have proven to be a financially promising citrus crop. Market requirements for lemons are unique as they do not fall into the requirements for other citrus varieties. Lemons produce several crops per year and do not require maturity indexing. However, preference has been shown and premium prices have been paid for well coloured, elongated lemons with high juice percentages.

The everbearing characteristic of lemon trees results in a system of overlapping bud and floral formation. The changing environmental effects on trees results in no constant maturity period and regrowth responses between annual crop cycles. 'Eureka' lemon is one of the most vigorous growing cultivars, with highly spreading branches, resulting in the necessity to control lemon tree size. Trees need to be pruned to become more manageable and to address specific limiting factors concerning their structure and canopy function (physiology and canopy light distribution)

The primary effects of pruning are the reduction of bud number (Southwick and Davenport, 1987) and a concomitant change in shoot:root ratio (Tucker *et al.,* 1994). Most beneficial effects can be ascribed to changes in light and dominance relationships (Krajewski, 1996). Age and canopy position of buds affects sprouting and flowering responses. These closely linked factors affect the outcome of flower manipulation by pruning (Krajewski and Rabe, 1995b). Effects also depend on the time and severity of pruning (Krajewski and Rabe, 1995b).

The correct timing of pruning lemons in these complex cycles would be of great benefit, as growers would be able to control tree size without any detriment to crop value. To date, no practical means have been found to manipulate any factor other than fruit colour in lemons. Field observations suggest that the time at which lemon trees flower may affect time of maturity, colour, size and perhaps even fruit shape. Pruning lemon trees results in regrowth, which will flower and become fruitful once hardened off. Nothing is known about the effects of time of pruning regrowth**,** and hence on crop cycles, fruit size and shape, and internal/external quality factors.

CHAPTER TWO

MATERIALS AND METHODS

2.1 PLANT MATERIAL

The trial orchard was planted in 1989 at “Eluhlaza” in the Sundays River Valley (Eastern Cape, South Africa, 33.3°S 25.40°E, summer rainfall area, *ca.* 200 m altitude). ‘Eureka’ lemon on C. *volkameriana* rootstock, bearing a fifth and sixth commercial crop in 1999 and 2000 respectively, was used in this experiment. Each tree was selected for uniformity of size, vigour and crop load. Planting distance was 6.25 x 2 m (800 trees/ha). Trees had already filled their allotted space, canopy volumes ranged from *ca.* 4.5 to 9.0 m^3. 'Eureka' tree morphology is different to that of other lemon cultivars in that it has a less densely foliated, spreading canopy. Fruit quality is excellent when grown in coastal, Mediterranean-type climates. The rind is smooth and thin, and the fruit have high juice and acid levels (Davies and Albrigo, 1994.)

2.2 PRUNING TREATMENTS

Light pruning was applied by removing fresh mass without aggravating the root and foliage balance of the tree. The fresh mass (weighed total pruned material – weighed fruit) removed per pruning application was *ca.* 20 to 40 kg/tree. Pruning cuts removed poorly positioned, dysfunctional or dead branches on the trees. Heading cuts (removing the terminal bud) were made wherever possible below the intercalation on the axis of a simple stem (Plate 2). Bearing branch units were chosen for their correct spacing within the tree canopy and the potential to produce new vigorous growth. Complex lateral response arising on the bearing branch units were removed immediately after pruning. The reason for this removal was to enable accurate regrowth assessments at a later stage.

2.3 SELECTION OF DATA SHOOTS

Ten trees were hand pruned each month, starting December 1997 and ending in November 1998, referred to in this study as site one (Figure 1). The pruning treatments were repeated on adjacent rows in the same orchard from December 1998 until November 1999, referred to in this study as site two (Figure 2). The experimental layout of each site was in a random block design, consisting of a total of 120 trees. No control data shoots were selected as the research focus was on the timing of pruning. The heading cuts were made around the tree, each leaving pruned stubs of round wood 100 to 300 mm long, 8 to 18 mm basal diameter and bearing 4 to 12 axillary buds. Data shoots of the resulting lateral outgrowths (regrowth response) were tagged immediately after heading (Plate 1). These tagged branches are referred to as tagged potential branch bearing units (TPBBU) in this study. The total TPBBU consisted of ten data shoots per pruned tree and ten trees per treatment (n=100 TPBBU).

On each of the TPBBU, vegetative growth was measured by the increased shoot length from the pruning date. During September 1998 and 1999, sprouting percentage was determined as the percent of axillary sites sprouting per new growth unit (intercalation). On each of the TPBBU the flowers were counted during September 1998 and 1999 when the trees were in full bloom. During the harvest period in April 1999 and 2000, yield per tree (kg/tree) and fruit size (length:diameter ratio) were assessed. During this time, 20 fruit samples per treatment were removed from each tree to determine internal quality.

	Dec 97	Jan 98	Feb 98	Mar 98	Apr 98	May 98	Jun 98	Jul 98	Aug 98	Sep 98	Oct 98	Nov 98	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99
Milestones																		
Pruning treatment no. 1	◉																	
Pruning treatment no. 2		◉																
Pruning treatment no. 3			◉															
Pruning treatment no. 4				◉														
Pruning treatment no. 5					◉													
Pruning treatment no. 6						◉												
Pruning treatment no. 7							◉											
Pruning treatment no. 8								◉										
Pruning treatment no. 9									◉									
Pruning treatment no. 10										◉								
Pruning treatment no. 11											◉							
Pruning treatment no. 12												◉						
Vegetative response assessment										◉								
Flower response assessment										◉								
Fruit characteristic response assessment																	◉	◉

Figure 1. Diagrammatic representation of pruning treatments for site one. Ten trees were hand pruned each month, starting December 1997 and ending in November 1998. Data shoots of the resulting lateral outgrowths (regrowth response) were tagged immediately after heading on which vegetative, flower and fruit assessments where conducted.

	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99	Jun 99	Jul 99	Aug 99	Sep 99	Oct 99	Nov 99	Dec 99	Jan 00	Feb 00	Mar 00	Apr 00	May 00
Milestones																		
Pruning treatment no. 1	●																	
Pruning treatment no. 2		●																
Pruning treatment no. 3			●															
Pruning treatment no. 4				●														
Pruning treatment no. 5					●													
Pruning treatment no. 6						●												
Pruning treatment no. 7							●											
Pruning treatment no. 8								●										
Pruning treatment no. 9									●									
Pruning treatment no. 10										●								
Pruning treatment no. 11											●							
Pruning treatment no. 12												●						
Vegetative response assessment										●								
Flower response assessment										●								
Fruit characteristic response assessment																	●	●

Figure 2. Diagrammatic representation of pruning treatments for site one. Ten trees were hand pruned each month, starting December 1998 and ending in November 1999. Data shoots of the resulting lateral outgrowths (regrowth response) were tagged immediately after heading on which vegetative, flower and fruit assessments where conducted.

Plate 1. The heading cuts were made around the tree, each leaving pruned stubs of round wood 100 to 300 mm long, 8 to 18 mm basal diameter and bearing four to 12 axillary buds. Data shoots of the resulting lateral outgrowths (regrowth response) were tagged immediately after heading and are referred to as tagged potential bearing branch units (TPBBU). Response was studied on the subtending portion remaining after pruning.

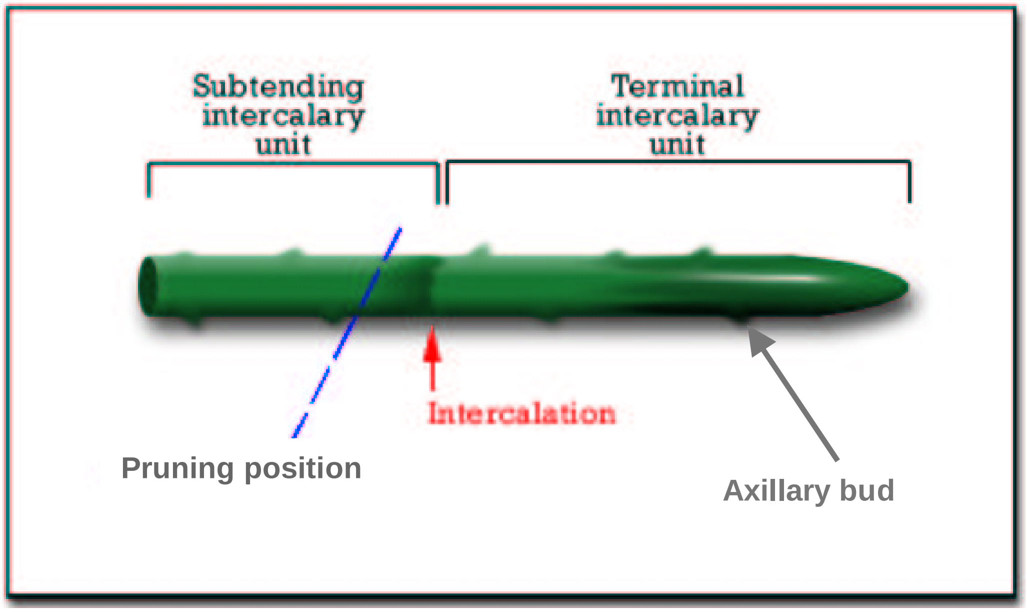

Plate 2. Schematic diagram of a lemon stem depicting leaf-axillary buds on the terminal and subtending intercalary units. Response was studied on the subtending portion remaining after pruning.

2.4 STATISTICAL METHODS

Statsgraphics Plus (version 1996) software was used to generate the following three different statistical methods used in this study.

2.4.1 Analysis of variance

Analysis of variance (ANOVA) parametric technique was performed to determine significant differences among the measured responses from the pruning treatments.

2.4.2 Analysis of proportions

Analyses of proportions were performed on the percent axils sprouting using logarithmic (LOGIT) transformations, according to the method of Snedecor and Cochran (1980).

Percent axils sprouting = log(no. of axils sprouting + 0.5) total no. axils present - no. axils sprouting + 0.5

Means were separated by least significant difference (L.S.D.).

2.4.3 Chi-squared test

The chi-squared test was generated to compare the observed frequencies of distribution. These would be expected if the null hypothesis of no association or statistical independence were true (Gomez and Gomez, 1984). By assuming the variables are independent, we can also predict an expected frequency for each cell in a contingency table (Easton and McColl, 1997). A chi-squared test was applied for fruit count distribution.

2.5 EXPERIMENTAL PROCEDURE FOR VEGETATIVE RESPONSE FROM PRUNING TREATMENTS

Indicators. Pruning trees causes regrowth, which provides structures that support flower development and ultimately support the lemon crop.

Data recorded. Thirty TPBBU from each treatment were assessed at 100 percent full bloom in September 1998 and 1999 on the following variables: a) the length of the TPBBU, measured from the applied cut to the first intercalation; b) The branch diameter measured within the first 10 centimetres of the TPBBU; c) the number of axillary buds on the TPBBU; d) the number of sprouted axillary buds on the TPBBU; e) the number of intercalation units on the regrowth from the sprouted axillary buds; and f) the length of each regrowth shoot and intercalary unit from the sprouted axillary buds.

The cumulative monthly heat units (H.U.) occurring over the period December 1997 to December 2000 were calculated to ascertain the exogenous influence on regrowth across treatments, where H.U. = (mean monthly temperature - 12.5˚C) x days in the month (Mendel, 1969).

Statistical analysis. ANOVA is a parametric technique (the values distribution written in terms of parameters) and was applied for TPBBU length, the number of axillary buds on the TPBBU, the number of intercalation units on the regrowth from the sprouted axillary buds, and the length of each regrowth shoot and intercalary unit from the sprouted axillary buds. Analyses of proportions were performed on the logarithmic (LOGIT) transformations for the percentage of total axils sprouting.

2.6 EXPERIMENTAL PROCEDURE FOR FLOWER RESPONSE FROM PRUNING TREATMENTS

Indicators. Assessment of flower on TPBBUs was counted to determine the influence of the pruning treatments on the flowering number.

Data recorded. Thirty TPBBUs from each treatment were assessed for the number of flowers present. The assessment was conducted at 100 percent full bloom on 8 October 1998 and 28 September 1999 (spring in the southern hemisphere). The total number of flowers per TPBBU were counted, the data ranged from zero (no flowers) to 33 flowers per TPBBU. The number of flowers on each TPBBU were indexed per 100 axillary sites.

Statistical analysis. The value distribution could be written in terms of parameters. Results were calculated by using the parametric ANOVA technique on the total number of flowers on TPBBUs.

2.7 EXPERIMENTAL PROCEDURE FOR FRUIT CHARACTERISTIC RESPONSE FROM PRUNING TREATMENTS

Indicators. Trees producing large fruit can produce proportionally lower yield. Fruit size is a crucial factor in quality-conscious markets, but reduced income due to lower yields can also be financially detrimental to growers. In this study assessments were conducted on fruit characteristics; fruit yield, height, diameter, rind thickness and juice content to determine their response and the relationship they had on each other in the different pruning treatments.

Data recorded. Fruit were harvested on 15 April 1999 (harvest one) and 20 May 1999 (harvest two) from site one. The harvest was repeated on the second site on 11 April 2000 (harvest one) and 31 May 2000 (harvest two).

The weight of the fruit from each treatment was measured and 50 fruit were randomly collected for the following quality assessments: a) fruit length was measured from the style end to the fruit shoulder; b) fruit diameter; c) rind thickness; d) fruit weight; e) fruit weight after extracting the lemon juice; and f) endoxerosis assessment.

Fruit shape ratio was calculated by dividing the fruit length by fruit diameter. Monselise (1977) found that lemon shape was more elongated with high promotive activities and large differences in day/night temperatures. This association was for fruit maturing during autumn and early winter. In this study, fruit elongation was assessed to see if the timing of pruning and the development of the response would be affected by the day/night temperatures. The lemon juice was extracted with a hand juice extractor. Fruit juice percentage was calculated by the proportion of fruit juice weight to fruit weight. Exported fruit is separated by count values, which represent the number of fruit that fill a carton. Fruit samples were divided into large fruit count (69 to 75 mm diameter), medium fruit count (56 to 68 mm diameter) and small fruit count (48 to 58 mm diameter). The number of medium sized fruit from the collected samples was used per treatment. The reason for selecting the medium sized fruit as a benchmark was because it was the highest paying count during the 1999 season. Fruit maturity period was determined by the proportions of crop yields falling into first or second harvest in either year. The crop value was calculated by multiplying the yield by the count value. The medium sized fruit value was obtained from the average Middle East lemon market prices during weeks 16 and 20, 1999. The assessed treatments were grouped to present crop value per season.

Statistical analysis. The analysis of variance statistical parametric technique (the values distribution written in terms of parameters) was applied for yield, fruit ratio, rind thickness, juice percentage and count distribution. The Chi-squared test was applied for count distribution.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 REGROWTH LENGTH AND COMPLEXITY

Three natural vegetative flushes occurred between the date of first treatment (1 December 1997) and the date of the assessment (12 September 1998). The first vegetative flush occurred in November/December, the second in February/March and the third in August/September. No control data shoots were selected, therefore influence on the effect of heading cuts on the time of flushes was not measured. The age of the pruned tagged bearing branch units ranged from 1 to 10 months. The sprouting length characteristic range included regrowth lengths between 0 (no growth) to 715 mm. Applying heading cuts in summer resulted in the longest shoot regrowth. Regrowth shoots averaged between 52.3 and 59.7 mm for trees pruned in January and February 1998 (Figure 1). The January and February 1999 regrowth shoots averaged between 68.6 and 89.9 mm respectively (Figure 2).

Applying heading cuts from April onwards for both the 1998 and 1999 research sites resulted in shoots one-half to one-third as long as December to March heading cuts. Complexity was determined by the proportion of the number of new regrowth stems per sprouted axil and was expressed in a ratio format. The complexity at the 1999 assessment peaked in January (2.12:1) and peaked in March (1.39:1) in 1999 assessment (Figures 3 and 4). There is a correlation between average regrowth and regrowth complexity, as both year's heading cuts resulted in a decrease of average regrowth and regrowth complexity from April onwards. Shoots arising from the summer heading cuts were more highly complex than those arising from heading cuts at any other time (Figures 3 and 4), as evidenced by the increased in shoot length and number of new stems following summer pruning.

The implication of this finding is that lemon growers can manipulate the tree through pruning in summer to increase branch complexity so that the tree may produce more bearing sites for flowers and hence greater crop. Conversely, the grower can take advantage of pruning in winter if the trees are young and vigorous to minimize branch complexity. Vigorous growing trees are more susceptible to over-crowding and pruning during summer could lead to over-crowding and dense canopies. Over-crowding of trees can have a detrimental effect on harvesting costs, as it is more labour intensive to harvest fruit from dense canopies. Dense trees also provide too many branches that tend to have higher contact with the fruit skin and hence cause cosmetic damage.

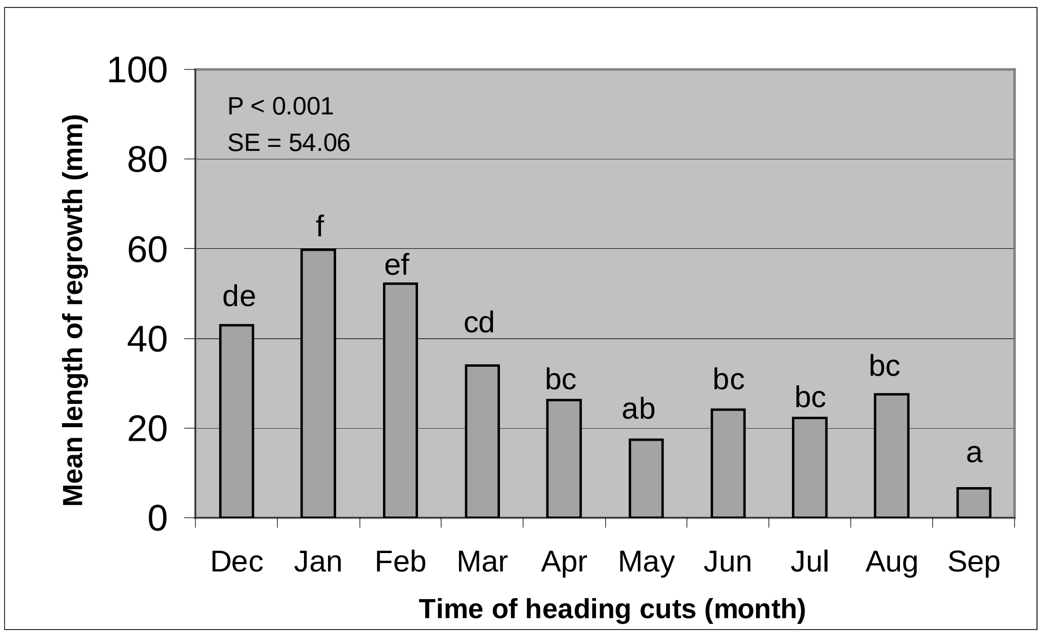

Figure 1. Effect of time of heading cuts on mean length (mm) of resulting lemon shoot regrowth shoots in the Sundays River Valley. Trees were pruned December 1997 to September 1998 and were assessed September 1998. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means sharing a common letter are not different at the 5% level of significance. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

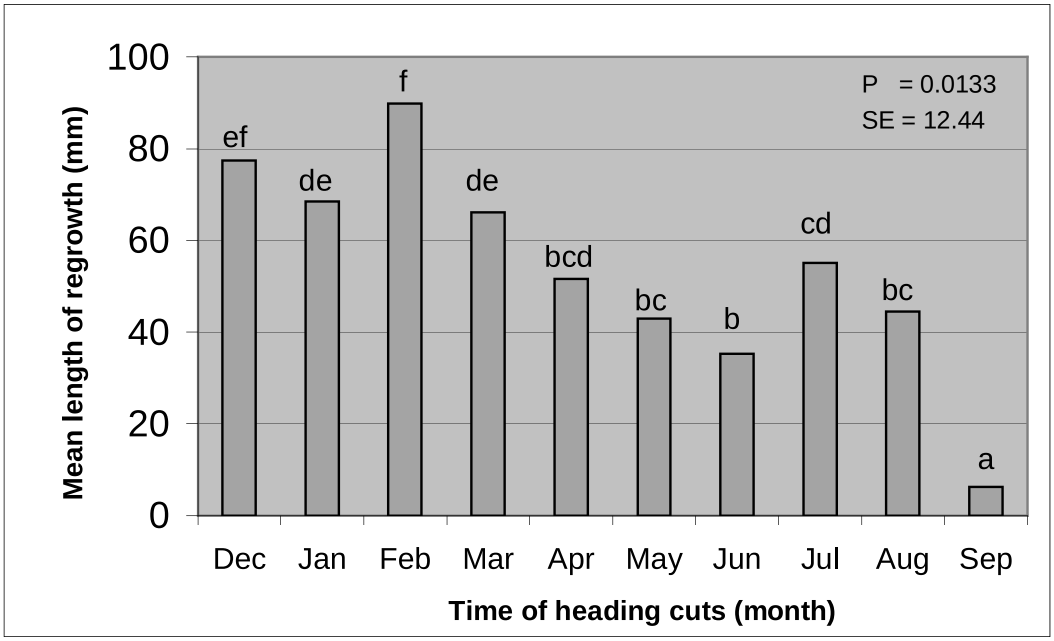

Figure 2. Effect of time of heading cuts on mean length (mm) of resulting lemon shoot regrowth shoots in the Sundays River Valley. Trees were pruned December 1998 to September 1999, and were assessed September 1999. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means sharing a common letter are not different at the 5% level of significance. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

3.2 SPROUTING

In the 1998 assessment, the percent of total axils sprouted was lower for December to March treatments than the June to September treatments (Figure 5 and 6). In Figure 6 more sprouting is observed in 1999; a significantly lower proportion of axils sprouted (45 percent) on shoots resulting from December/January than those arising from heading cuts in August/September which had a sprouting percentage of 60 percent. Sprouted axillary sites arising from the summer heading cuts were less than those arising from heading cuts at any other time (Figure 5 and Figure 6). This is conversely what was found with the increased in shoot length over summer and it can be said that the heat units had no effect on sprouting of axils. The implication of this finding is that lemon growers that prune lemon trees in winter will produce more branch bearing units that are subtending from main branches, these will be less complex and shorter than the branches pruned in summer.

3.3 HEAT UNITS AND VEGETATIVE RESPONSE

Shoot growth length (Figure 1 and 2) and complexity response (Figure 3 and 4) appeared to correlate closely to heat unit accumulation (Figures 7 and 8). Regrowth mean length and number of new regrowth stems per sprouting axils declined significantly from April 1998 and 1999. Heat unit accumulation for April 1998 and 1999 was 1060 H.U. and 1241 H.U., respectively. This association suggests that the reduction of the rate of vegetative development could occur in the region of *ca.* 1000 to 1200 H.U., and confirms the calculated "minimum" range for vegetative growth (minimum range 1000 to 1400 H.U., and maximum range of 5000 to 6000 H.U.) (Mendel, 1969).

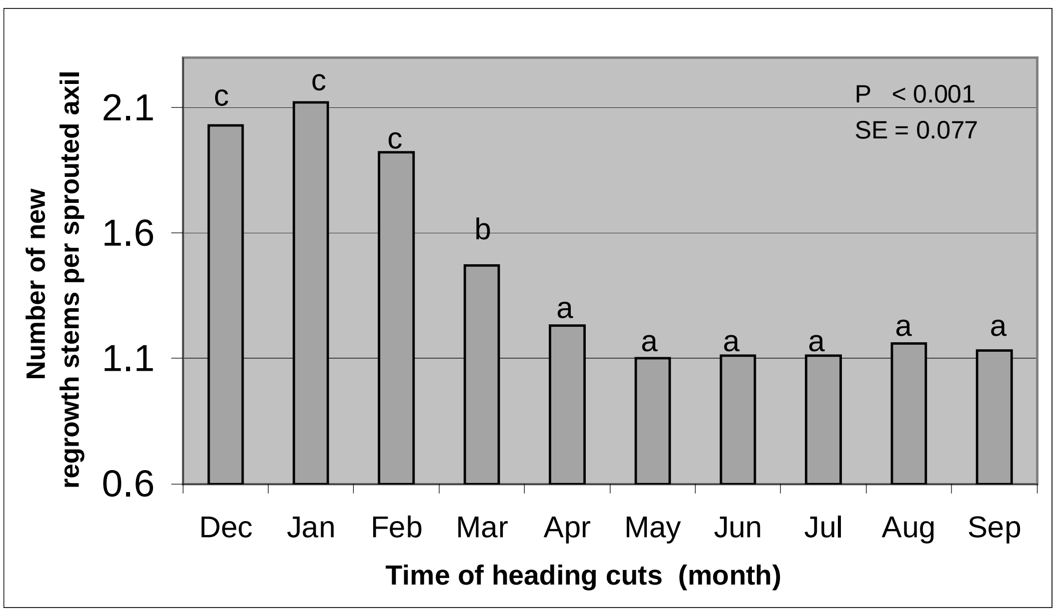

Figure 3. Effect of time of heading cuts on the number of new regrowth stems per sprouted axil. Trees were pruned December 1997 to September 1998 and were assessed September, 1998. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

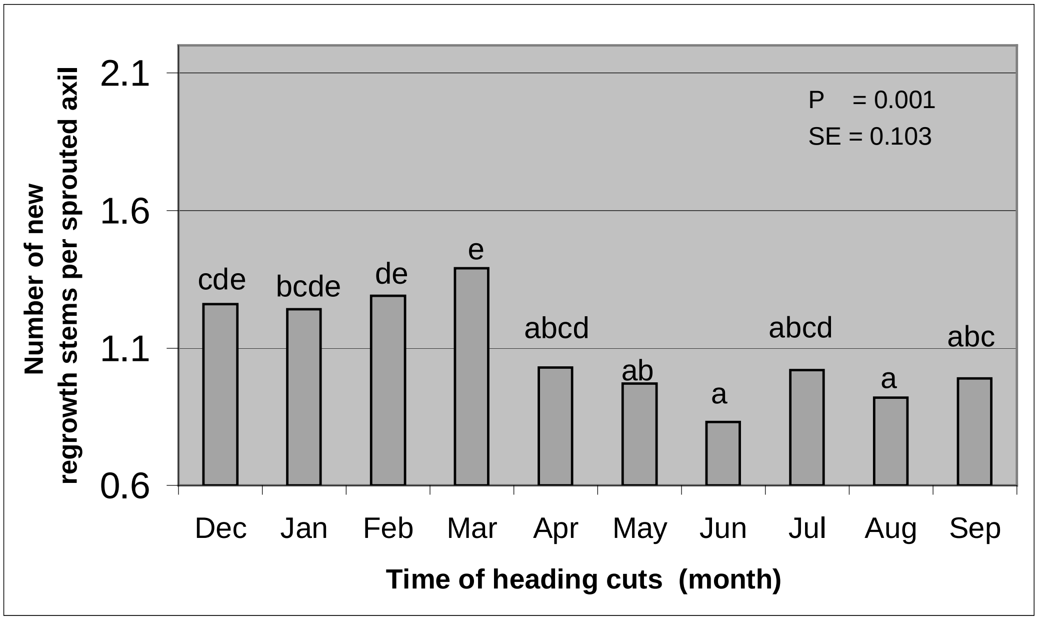

Figure 4. Effect of time of heading cuts on the number of new regrowth stems per sprouted axil. Trees were pruned December 1998 to September 1999 and were assessed September, 1999. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

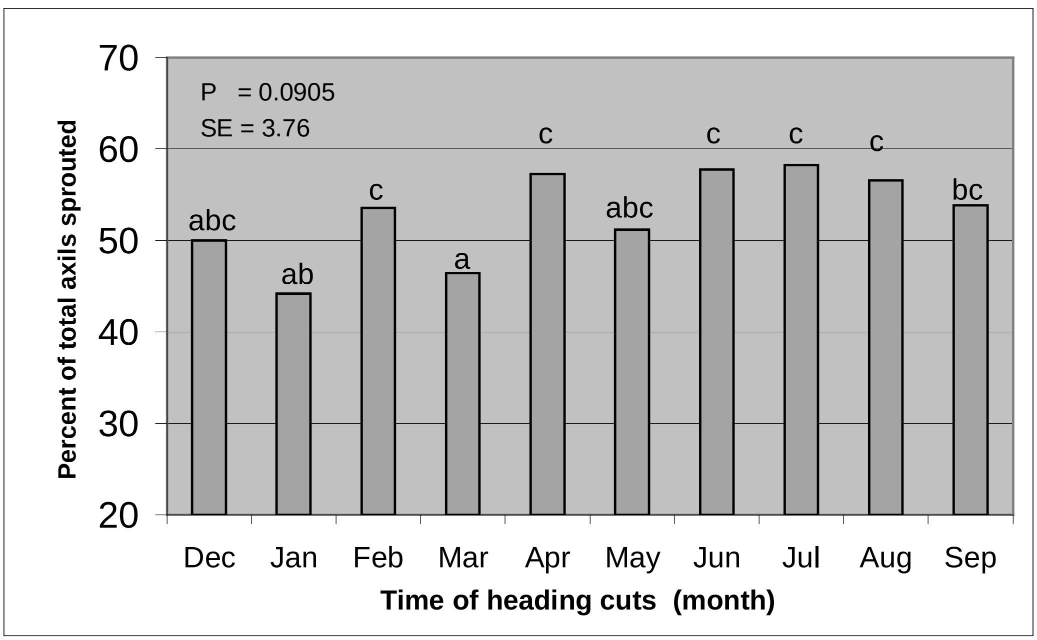

Figure 5. Effect of time of heading cuts on the percent of total axils sprouted of resulting lemon regrowth shoots. Trees were pruned December 1997 to September 1998 and were assessed September, 1998. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

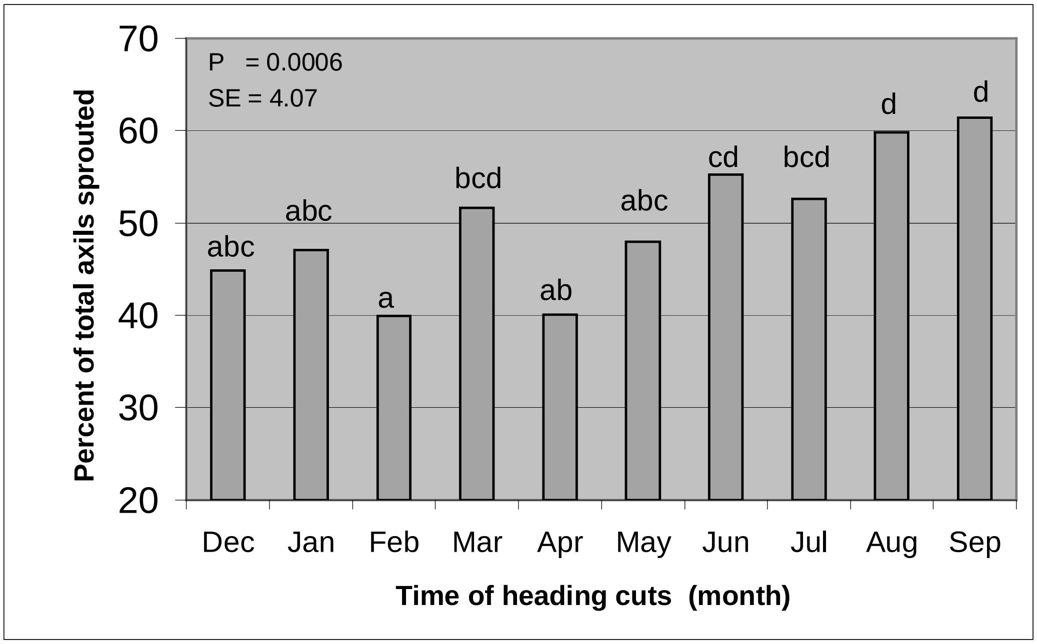

Figure 6. Effect of time of heading cuts on the percent of total axils sprouted of resulting lemon regrowth shoots. Trees were pruned December 1998 to September 1999 and were assessed September, 1999. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

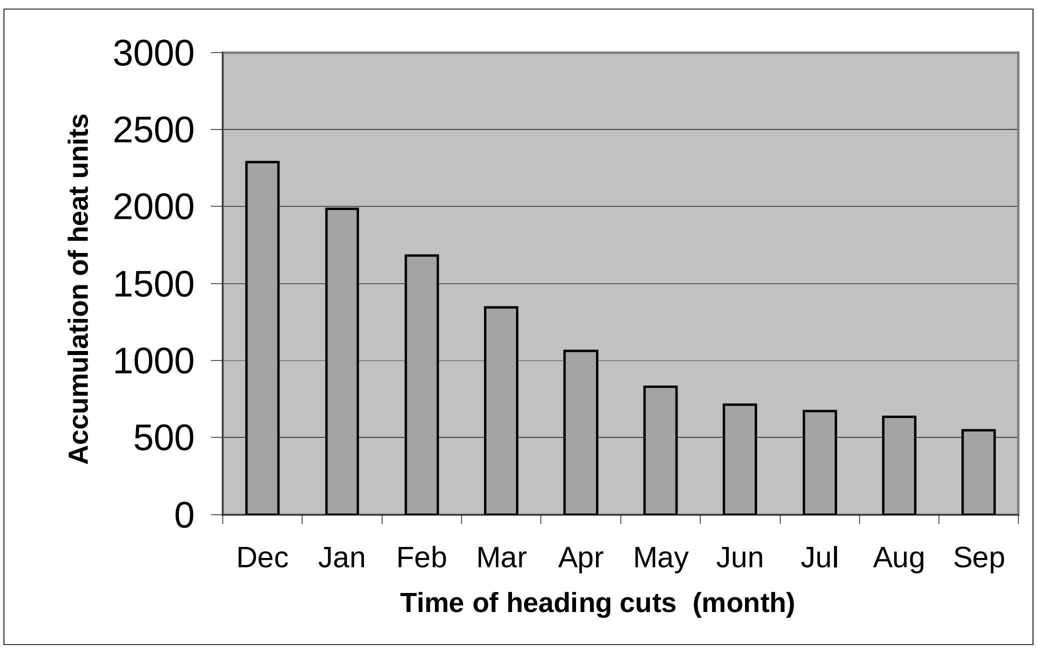

Figure 7. Accumulation of heat units [(mean monthly temperature - 12.5 °C) x days/month)] (Mendel, 1969) from December 1997 to September 1998 for the lemon orchard used in this study. Only the treatment months were analysed for H.U. The temperature data was received from the South African Weather Services station in Addo, *ca.* 10 km from the research site.

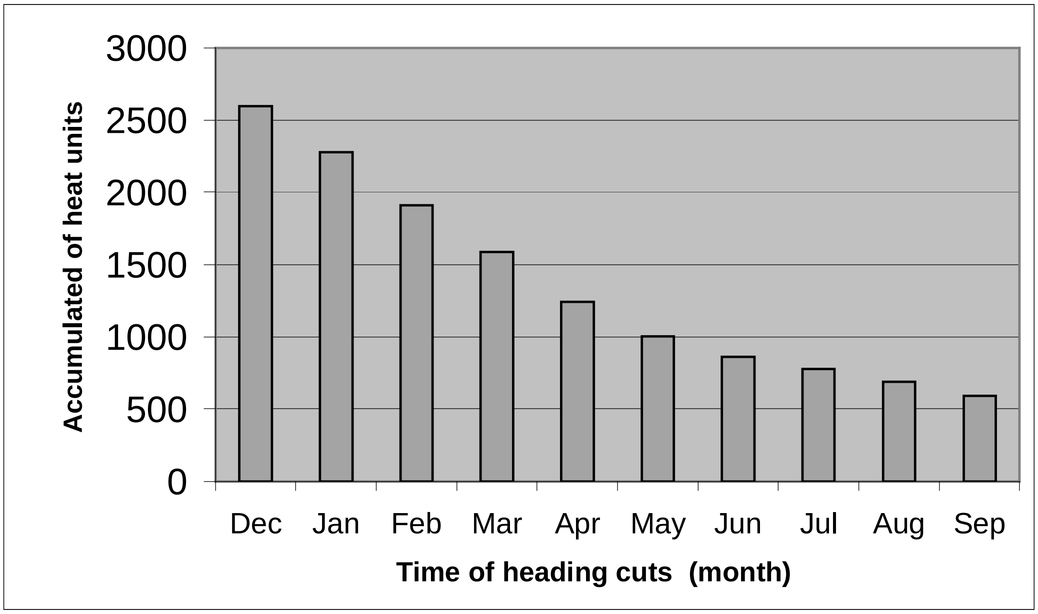

Figure 8. Accumulation of heat units [(mean monthly temperature - 12.5 °C) x days/month)] (Mendel, 1969) from December 1998 to September 1999 for the lemon orchard used in this study. Only the treatment months were analysed for H.U. The temperature data was received from the South African Weather Services station in Addo, *ca.* 10 km from the research site.

The results also support research findings on the influence of higher temperature on vegetative development of *Citrus* trees (Mendel, 1969). Flushes produced in summer under conditions of high temperatures have a greater number of internodes, and the internodes are longer. Hence, branches produced under high temperatures are longer. Therefore, timely pruning in summer therefore creates vegetative stimulation at a time of maximum vegetative growth potential.

3.4 FLOWER RESPONSE

The time of heading cuts affected the number of flowers borne on the resulting regrowth once the regrowth had hardened off and undergone winter rest and then sprouted the following spring. In both years, the highest number of flowers occurred following summer heading cut treatments. In 1998, over 140 flowers per 100 axillary sites were recorded for December and January treatments (Figure 9), and over 100 flowers per 100 axillary sites for December and January treatments in 1999 (Figure 10). Heading cuts from February (eight-month-old heading cuts) onwards resulted in significantly fewer flowers than December and January treatments; typically one-third to one-fifth the number of flowers.

Lovatt *et al*. (1984) found similar results with higher flower numbers on twelve-month-old wood, and Guardiola, J.L., C. Monerri, and Agusti M. (1982) found that summer (8 months) or fall (5 months) flushes produced the maximum flowers. However, Moss (1976) and Guardiola *et al.* (1982) ascribed most flowering to the second year growth flush. These conflicting findings are possible as the number of flowers may differ due to position of bearers within the canopy or previous crop patterns (Krajewski and Rabe, 1995a). The maximum flowering occurred on the summer flushes. Applying heading cuts to terminal shoots allowed axillary sites on the subtending units to sprout vegetative shoots (Krajewski and Rabe, 1995a). The most productive trees are those which produce large numbers of leafy inflorescences and vegetative shoots, thus ensuring a good crop in the current season, and plentiful growth the following year (Sauer, 1951). The benefit of increasing the floral intensity and fruit set would ultimately be to increase yield.

The regrowth from the December/January heading cuts were nine-to-ten-months old when the assessment was conducted in September. We can deduce that the vegetative response age was approximately 9 to 10 months and, according to Guardiola *et al.* (1982), flushes at this age bear the maximum flowers. This was confirmed when the complex vegetative responses formed from the December/January heading cuts provided the highest number of flowers of over 100 flowers per 100 axils (Figures 9 and 10). Whereas, the shorter and less complex shoots did not provide favourable conditions for flower formation and only formed an average of 30 flowers per 100 axils (Figures 9 and 10). Therefore, pruning early in the year, during summer, will increase the potential for flower formation on the lemon tree.

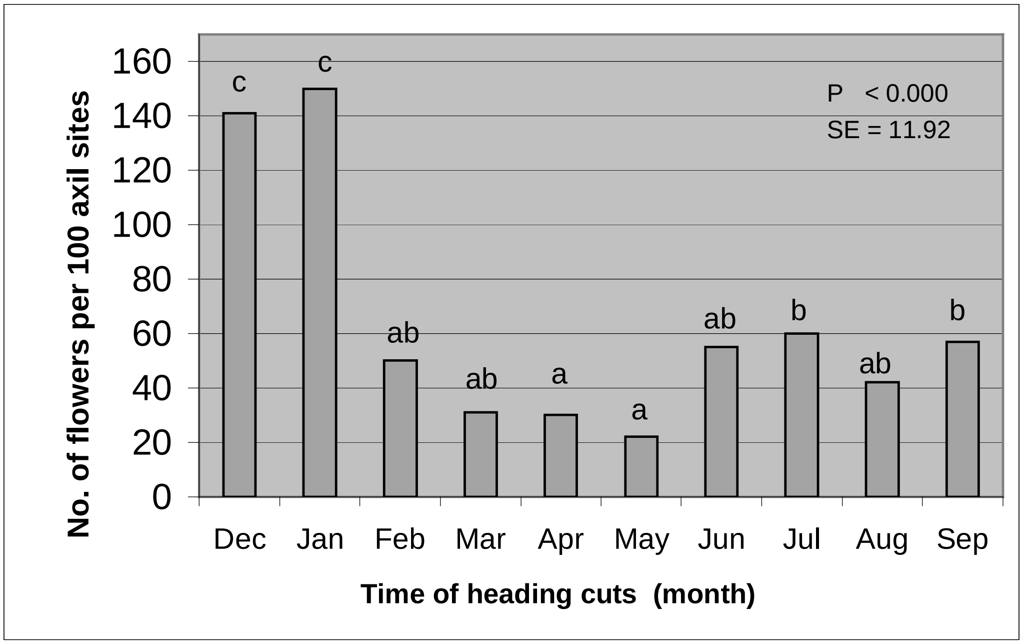

Figure 9. Effect of time of heading cuts on the number of flowers produced per 100 axils on resulting regrowth shoots. Trees were pruned December 1997 to September 1998 and were assessed September 1998. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

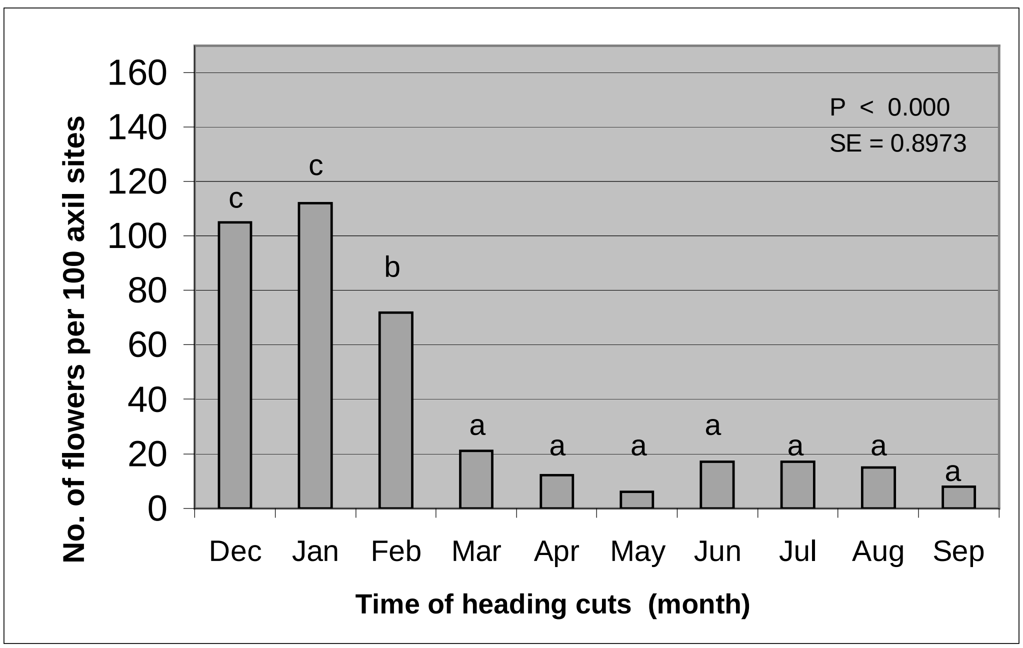

Figure 10. Effect of time of heading cuts on the number of flowers produced per 100 axils on resulting regrowth shoots. Trees were pruned December 1998 to September 1999 and were assessed September 1999. Treatment assessments for October and November were not conducted due to the fact that they had not been pruned yet. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 100 experimental units were used, consisting of 10 shoots per treatment.

3.5 FRUIT CHARACTERISTIC RESPONSE

There was no consistent trend in the effect of timing of pruning on fruit elongation among pruning treatments within each season and between seasons (Figures 11 and 12). Overall, the fruit produced during 1999 was more elongated than fruit produced during 2000. With the exception of the January pruning, all the other pruning times 1998 resulted in fruit shape ratio exceeding the required ratio of 1:1.25 (I. Moore, personal communication, 1997). Whereas, the fruit shape ratio was less than 1:1.25 in the next season for all pruning times except January (Figures 11 and 12).

Fruit juice percentage exceeded the required quality standard for lemons of 40 percent (Van Wyk, 2000) for all treatments and in both years (Figures 13 and 14). Overall, juice percentages were considerably higher during 2000 (62.3 percent) than during 1999 (54.7 percent). This seasonal difference was possibly due to higher soil moisture in 2000. No consistent trend in the effect of timing of pruning on juice percentage among pruning treatments within each season and between seasons occurred. No consistent trend in the effect of timing of pruning on fruit rind thickness among pruning treatments within each season and between seasons occurred (Figures 15 and 16).

Applying heading cuts to lemons did not consistently affect fruit size (Table 1, 2 and 3). Fruit size is an important quality factor. Therefore, an “adequate size” significantly improves quality and consequently higher prices can be realised in the market. Research on manual thinning on ‘Satsuma’ mandrins by Zaragoza, Trénor, Alonso and Primo-Millo (1992) showed that pruning increased fruit size, and the size increased with increased pruning severity. Such effects of pruning on fruit diameter could possibly be a result of the reduction in competition between fruits, resulting in more growth, which was not found in this study.

The December heading cuts produced the highest yield in both seasons compared with the other months (Figures 17 and 18). The highest yields associated with summer pruning supports data obtained on flowering responses of summer regrowth (Figures 9 and 10). This confirms findings by Sauer (1951) that the most productive trees are those which produce large numbers of leafy inflorescences and vegetative shoots, thus ensuring a good crop in the current season, and plentiful growth the following year. The benefit of increasing the floral intensity has increased yield.

Differences in fruit yield among treatments stabilized by the second year after the first heading cut application (Figure 19). This indicates that biennial pruning would result in no significant difference in yields as opposed to annual pruning. Young and Koo (1975) found that biennial hedging of the eastern half of lemon trees produced greater yields than the western half, regardless of when hedged. Similar results were found with experiments on unpruned and pruned lemons over a five-year-period, where the control resulted in a higher yield than the pruned trees (Chandler, 1950). The unpruned trees did however produce tangled, broken and dead branches, which are one of the main causes of poor fruit rind cosmetic quality. The initial reduction in yield may be a result of the pruning of bearing branches. Time of pruning did not effect the proportion of fruit harvested earlier (April) vs. later (May) (Figures 20, 21 and 22).

The relationship between 1997/1998 heading cut applications and crop value where calculated by using free on board[1] Capespan Middle East prices during weeks 16 and 20 (packout of 75 percent was used). The summer treatments produced the highest income, with both years' summer pruning applications producing over R100 000 per hectare (Figures 23 and 24). Although real market returns were used in this theoretical exercise, the difference in crop value among pruning treatments was ascribed not to differences in fruit size or quality, but mainly to an increase in yield due to pruning in the summer months.

[1] Seller is responsible for all costs and risks involved with having the goods delivered 'over the ship's rail.

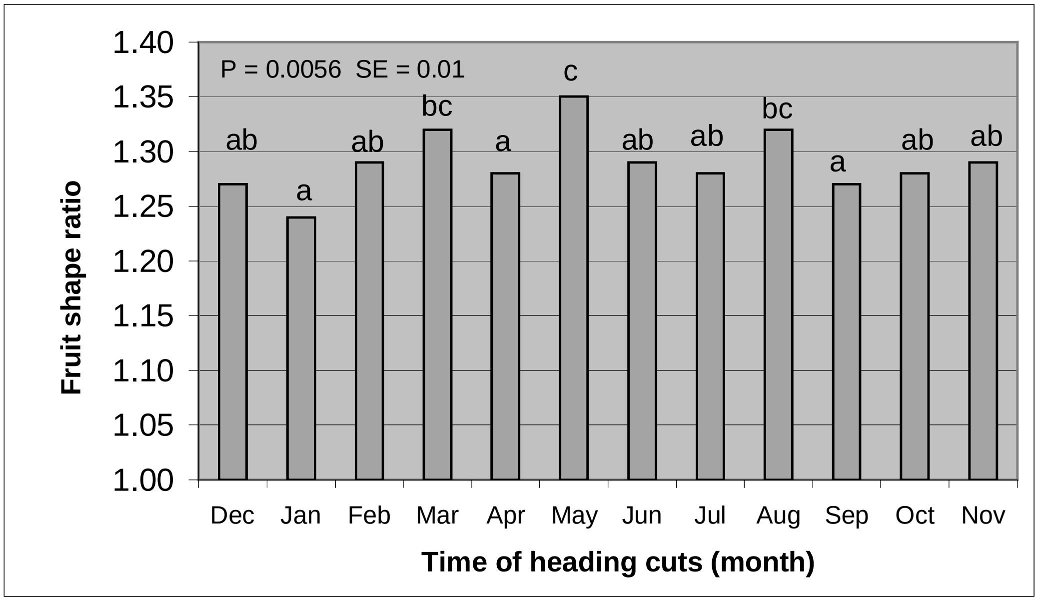

Figure 11. Effect of heading cuts on fruit shape ratio of resulting lemon regrowth shoots. Trees were pruned December 1997 to November 1998 and were assessed April and May 1999. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance(n=50 fruit per treatment).

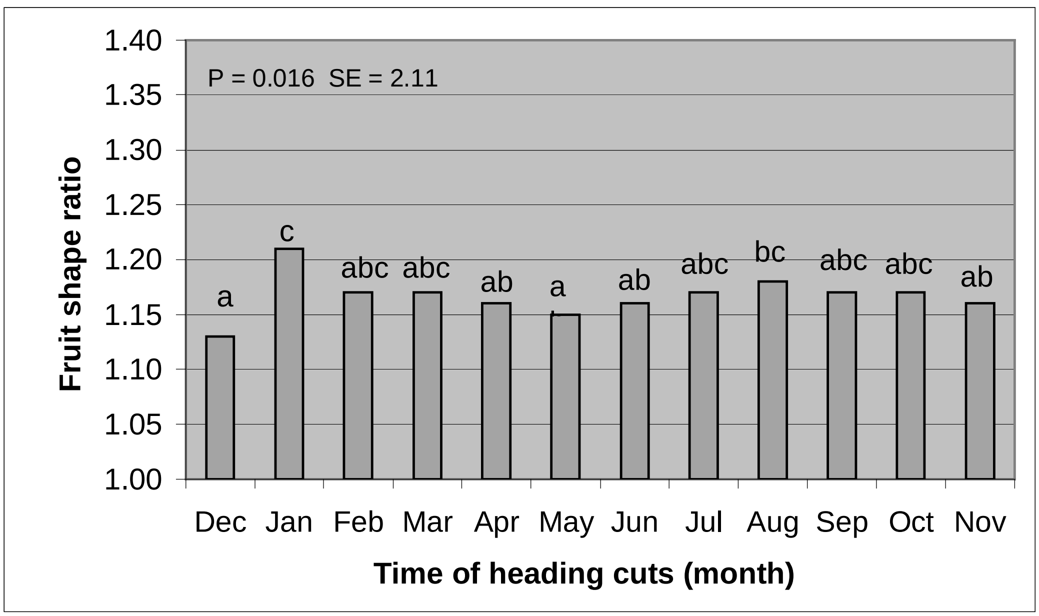

Figure 12. Effect of heading cuts on fruit shape ratio of resulting lemon regrowth shoots. Trees were pruned December 1998 to September 1999 and were assessed April and May 2000. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=50 fruit per treatment).

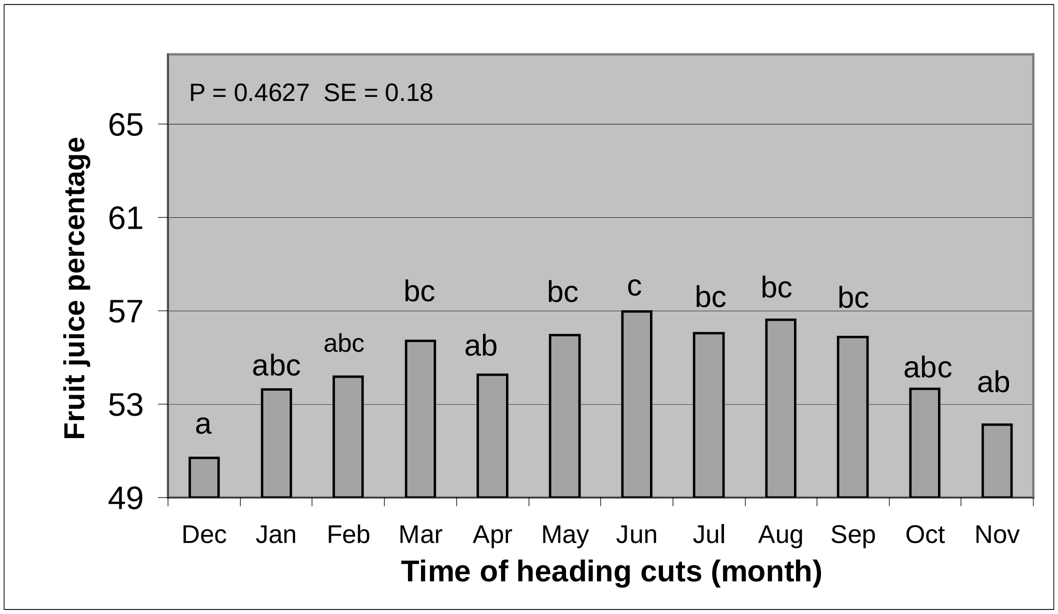

Figure 13. Effect of heading cuts on fruit juice percentage of resulting lemon regrowth shoots. Trees were pruned December 1997 to September 1998 and were assessed April and May 1999. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=50 fruit per treatment).

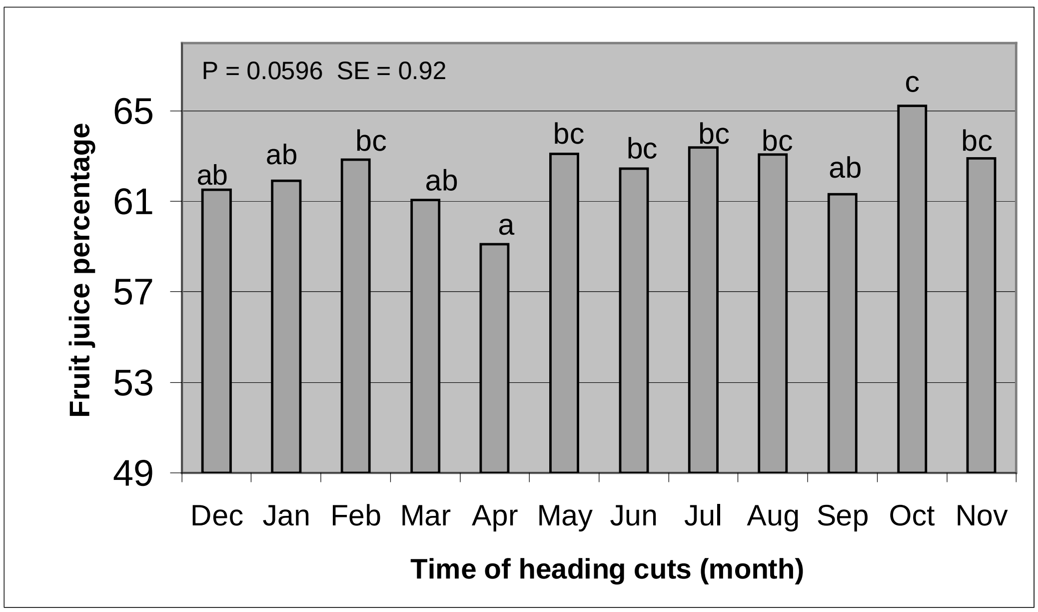

Figure 14. Effect of heading cuts on fruit juice percentage of resulting lemon regrowth shoots. Trees were pruned December 1998 to September 1999 and were assessed April and May 2000. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=50 fruit per treatment).

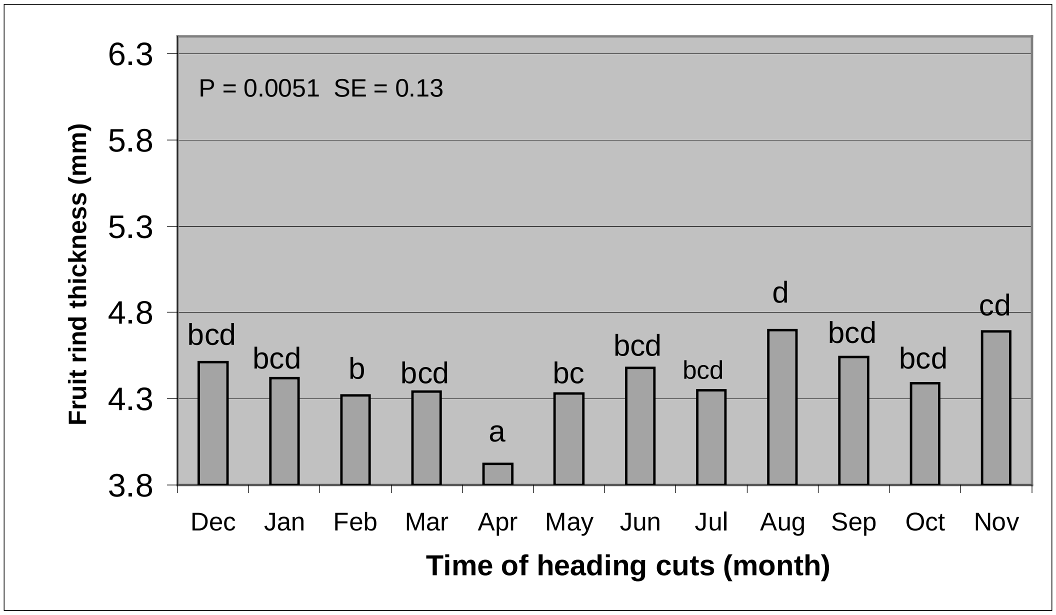

Figure 15. Effect of time of heading cuts on fruit rind thickness of resulting lemon regrowth shoots. Trees were pruned December 1997 to November 1998 and were assessed April and May 1999. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=50 fruit per treatment).

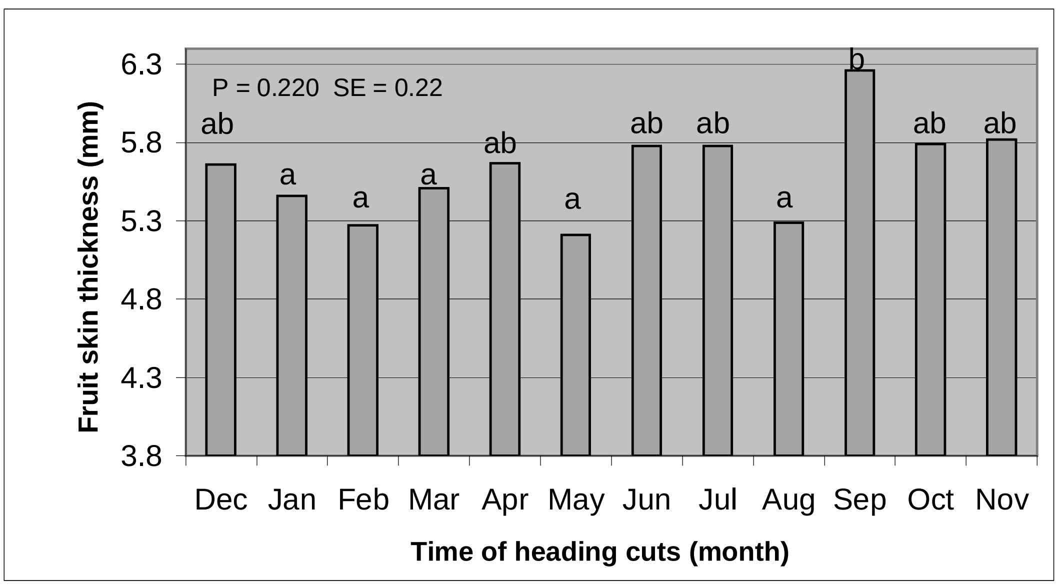

Figure 16. Effect of time of heading cuts on fruit rind thickness of resulting lemon regrowth shoots. Trees were pruned December 1998 to September 1999 and were assessed April and May 2000. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=50 fruit per treatment).

Fruit Size	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Small	62	28	40	42	66	30	32	52	42	40	42	44
Medium	38	68	60	56	34	66	62	44	56	56	48	54
Large	0	4	0	2	0	4	6	4	2	4	1	2

Table 1. Effect of time of heading cuts on fruit size distribution (%). Trees were pruned December 1997 to November 1998 and were assessed April and May 1999. Chi-squared procedure performed on cross tabulation presenting percentage breakdowns. Rows and columns are not independent at the 99% confidence level. $x^2 = 43.46$. P-value = 0.004. Large = count 64, 75, 88. Medium = count 100, 113, 138. Small = count 162, 189, 216.

Fruit Size	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Small	26	24	28	18	22	28	18	14	26	12	30	16
Medium	50	60	64	48	44	58	58	72	56	66	54	72
Large	24	16	8	34	34	14	24	14	18	22	16	12

Table 2. Relationship between heading cuts on fruit size distribution (%). Trees were pruned December 1998 to November 1999, and were assessed April and May 2000. Chi-squared procedure performed on cross tabulation presenting percentage breakdowns. Rows and columns are not independent at the 99% confidence level. $x^2 = 35.54$. P-value = 0.03. Large = count 64, 75, 88. Medium = count 100, 113, 138. Small = count 162, 189, 216.

Fruit Size	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Small	22	32	20	30	16	30	18	30	30	34	24	24
Medium	52	54	60	36	52	48	48	34	54	32	58	54
Large	26	14	20	34	32	22	34	36	16	34	18	22

Table 3. Effect of time of heading cuts on fruit size distribution (%). Trees were pruned December 1997 to November 1998, and were assessed April and May 2000. Chi-squared procedure performed on cross tabulation presenting percentage breakdowns. Rows and columns are not independent at the 99% confidence level. $x^2 = 31.26$. P-value = 0.09. Large = count 64, 75, 88. Medium = count 100, 113, 138. Small = count 162, 189, 216.

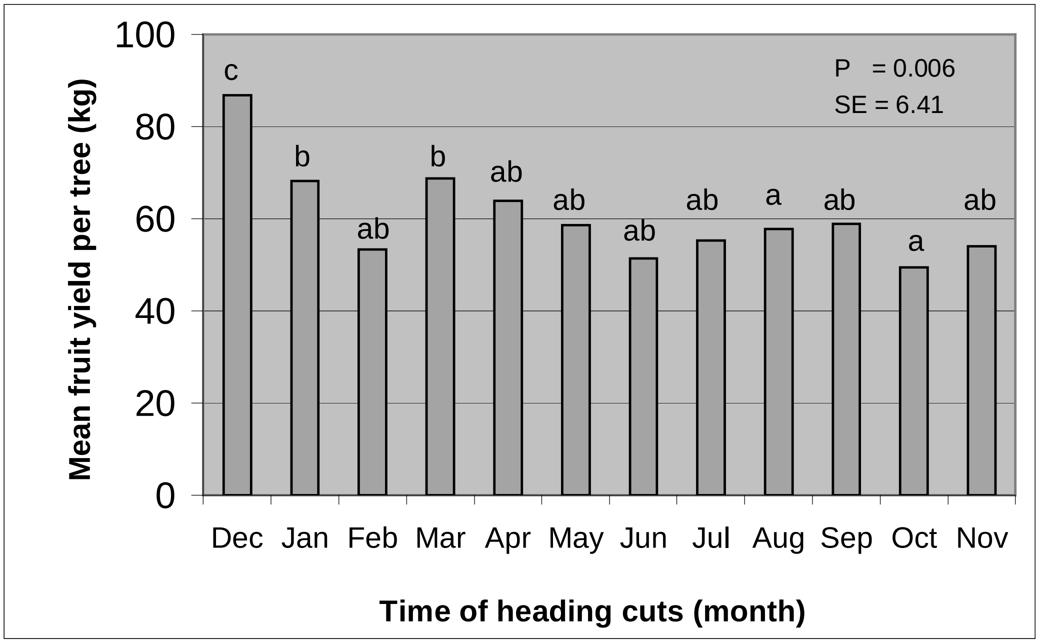

Figure 17. Effect of heading cuts between December 1997 and November 1998 on mean lemon yield (kg/tree) in April and May 1999. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 120 experimental units were used, consisting of 10 trees per treatment.

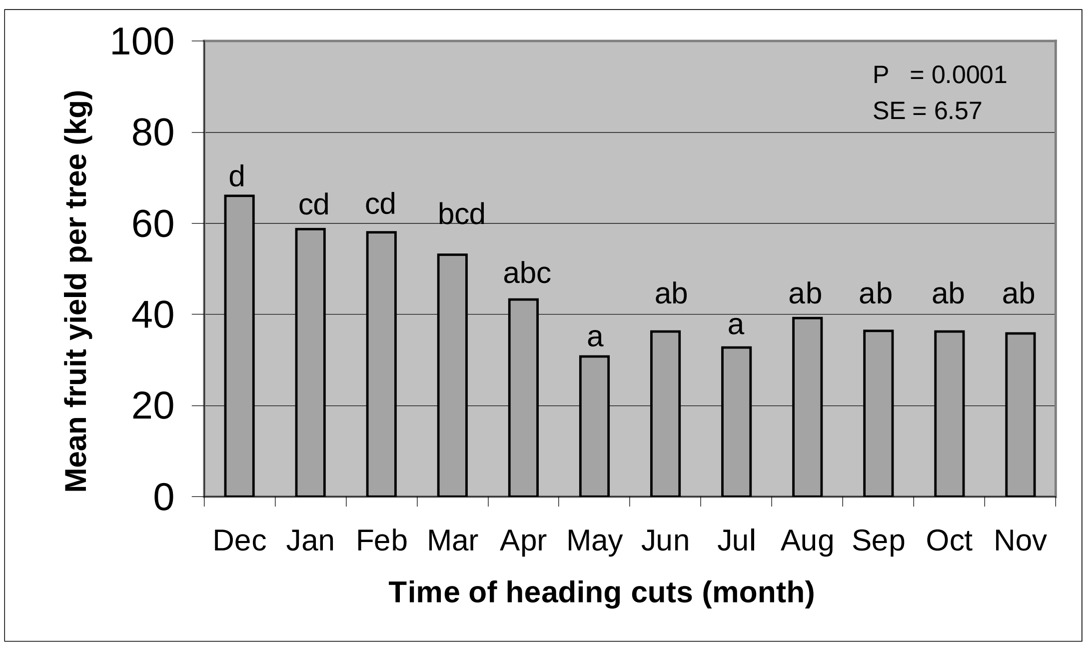

Figure 18. Effect of heading cuts between December 1998 and November 1999 on mean lemon yield (kg/tree) in April and May 2000. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 120 experimental units were used, consisting of 10 trees per treatment.

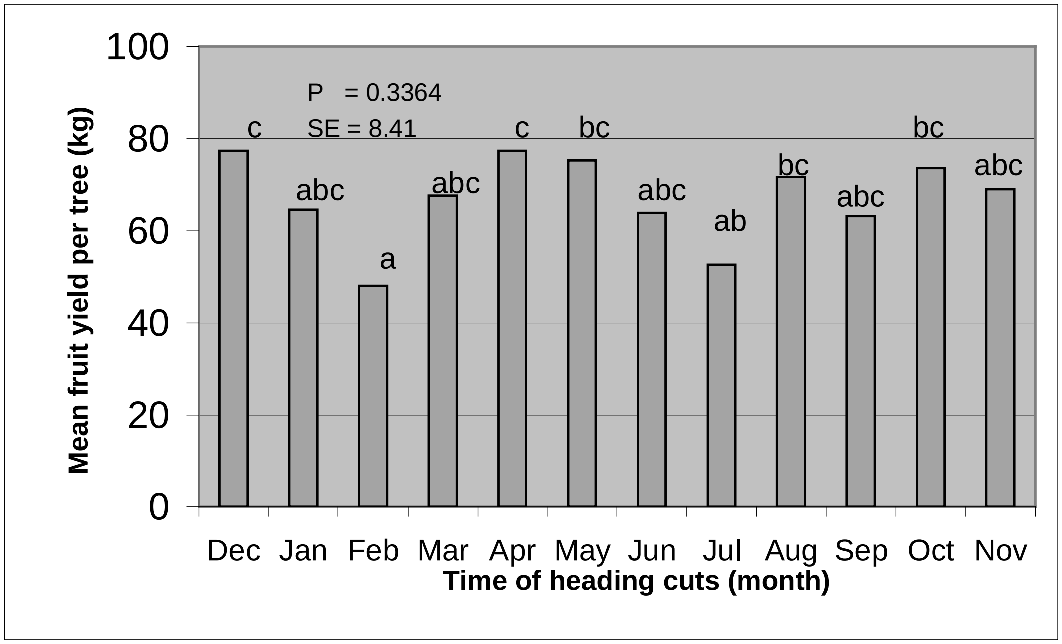

Figure 19. Effect of heading cuts between December 1997 and November 1998 on mean lemon yield (kg/tree) in April and May 2000. Means followed by different letters differ significantly (P<0.05) using the L.S.D. test. Total of 120 experimental units were used, consisting of 10 trees per treatment.

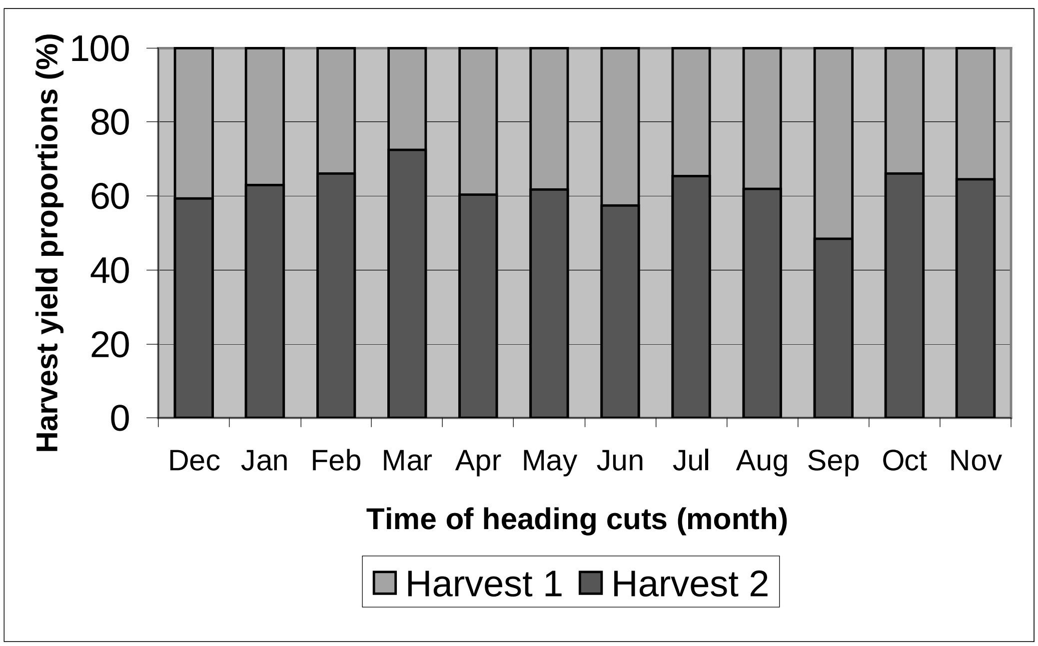

Figure 20. Effect of time of pruning on fruit maturity resulting lemon regrowth shoots. Trees were pruned December 1997 to November 1998 and were assessed April and May 1999. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=10 trees per treatment).

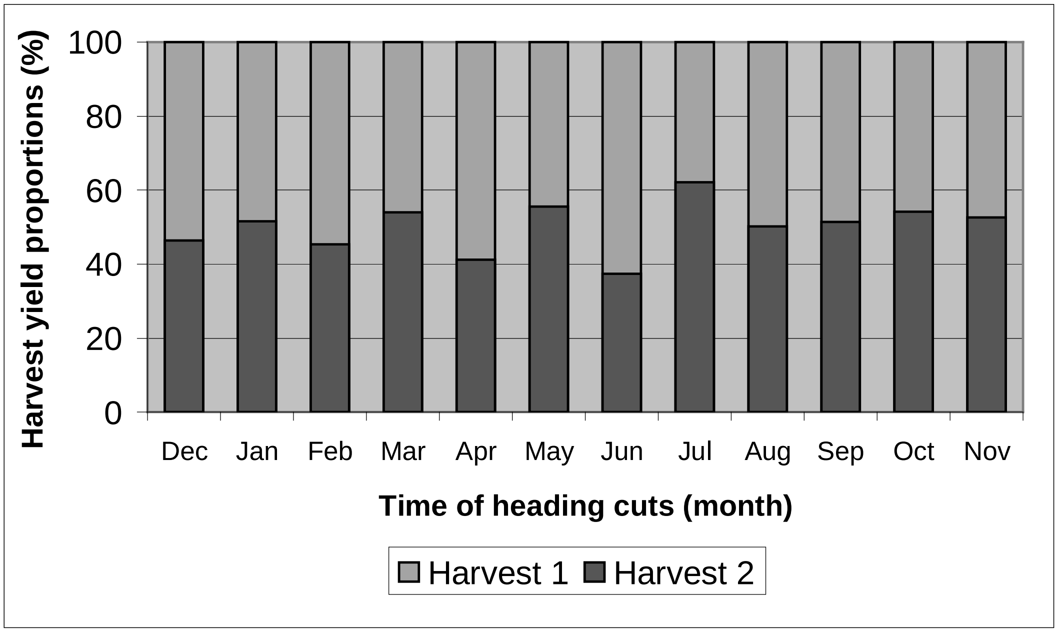

Figure 21. Effect of time of pruning on fruit maturity resulting of lemon regrowth shoots. Trees were pruned December 1998 to November 1999 and were assessed May to June, 2000. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=10 trees per treatment).

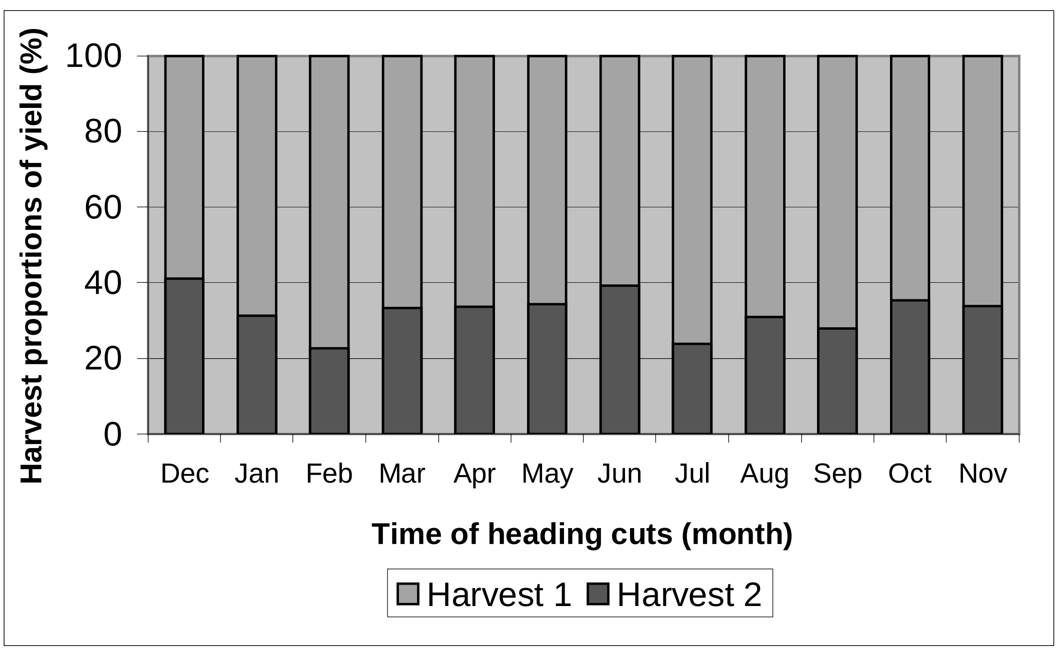

Figure 22. Effect of time of pruning on fruit maturity of resulting lemon regrowth shoots. Trees were pruned December 1997 to November 1998 and were assessed April and May 2000. Mean separation by Student-Newman-Keuls test. Means sharing a common letter are not different at the 5% level of significance (n=10 tress per treatment).

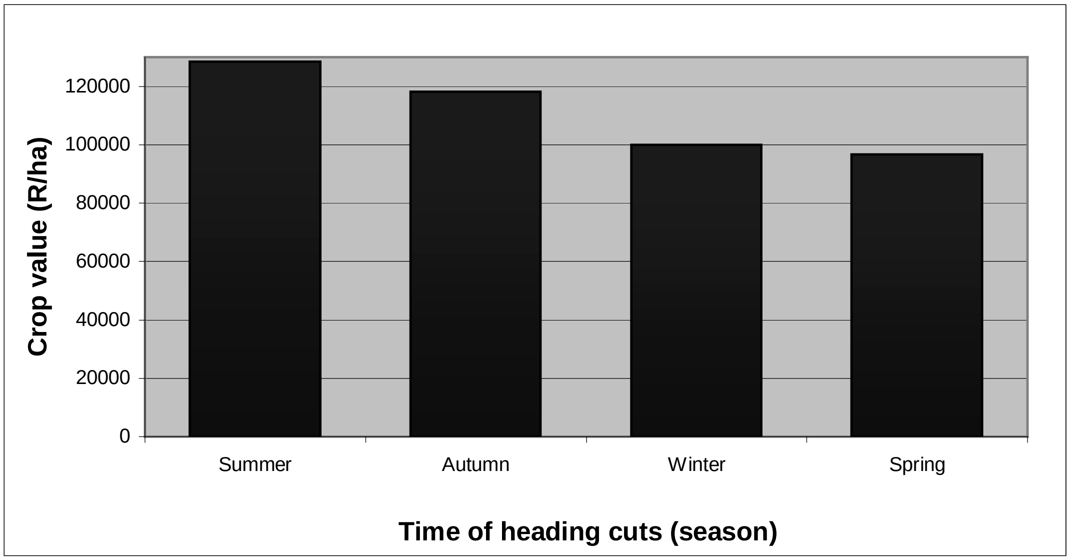

Figure 23. Relationship between heading cut applications in 1997/1998 and crop value. Rands per hectare calculated by 1999 free on board Capespan Middle East prices during weeks 16 and 20 (packout of 75%).

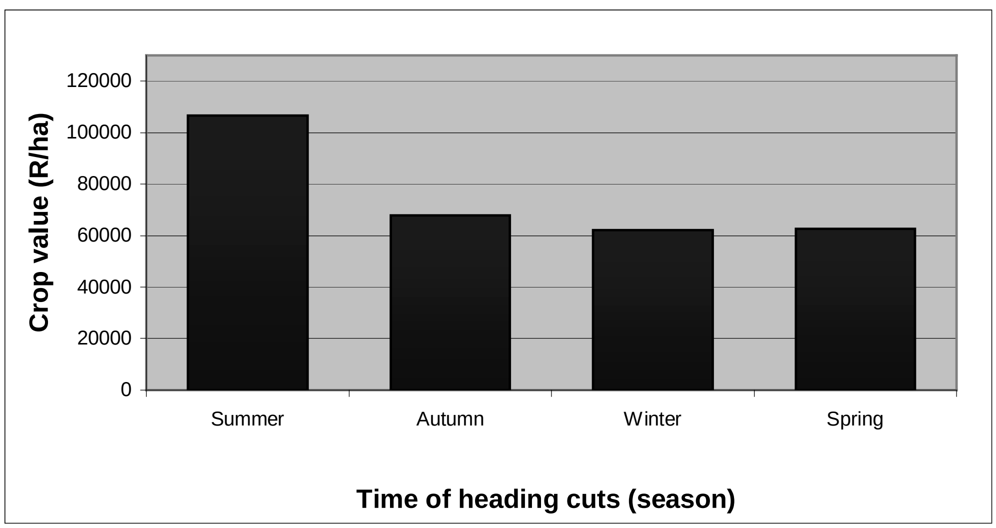

Figure 24. Relationship between 1998/1999 heading cut applications and crop value. Rands per hectare calculated by 1999 free on board Capespan Middle East prices during weeks 16 and 20 (packout of 75%).

CONCLUSION

Selective pruning has been identified as the cultural practice likely to have the most impact on producing quality fruit. The main objective of this study was to obtain a practical means of pruning lemon trees at the right time to produce fruit for export markets. Fruit quality is a subjective concept, dependent on market demand, and involves a number of traits such as fruit size, rind colour, fruit shape, juice content and acidity.

In this study, the effect of time of pruning lemon trees showed no consistent effect on juice percentage, fruit rind thickness, fruit shape ratio and fruit maturity period. However, in 1999, rinds were thinner, juice content was lower and fruit shape ratio indicated more elongated fruit than in 2000. These responses may have no correlation with the pruning treatments, but the seasonal differences observed may be because rounded lemons contain more juice than elongated lemons.

The findings on the relationship between rind thickness and fruit length contradicts Monselise *et al.* (1969) who found that in lemons, rind thickness increases with increased fruit length (elongated fruit). This research (Monselise *et al.,* 1969) was conducted on fruit that was harvested in summer in the northern hemisphere. This may suggest that the exogenous influences (climate) on lemon shape and rind thickness are different and therefore led to contradictory results.

Pruning lemons during the summer months showed significantly stronger vegetative response than those pruned during winter. The summer pruning treatments forced vigorous and complex new stems. The one-year-old and younger buds contributed significantly to the formation of spring shoots as found by Guardiola, Augusti and Garcia-Mari (1977).

There was a correlation between total cumulative heat units and vegetative regrowth. This confirmed the findings by Mendel (1969) that accumulated temperatures (heat units) above the physiological threshold for citrus trees (12.5°C) are decisive factors in growth rate. Heat unit accumulation for April 1998 and 1999 was *ca.* 1000 and 1200 H.U., respectively. This was accompanied by a decline in vegetative response. These findings confirmed the calculated "minimum" range for vegetative growth of 1000 to 1400 H.U. (Mendel, 1969). Therefore, it may be suggested that the rate of vegetative development in the Sundays River Valley declines from April due to the cumulative heat units falling below the "minimum" range for active vegetative growth (1000 H.U. to 1200 H.U.).

The short vegetative regrowth response following pruning in winter suggests that pruning in the colder season provides an environment for no excessive regrowth. Therefore, timeous pruning in winter could provide the grower with an opportunity to apply severe pruning cuts (*ca.* 100 to 180 mm diameter) to correct poor tree framework, without the repercussion of unfavourable regrowth.

The highly significant difference in number of flowers between treatment groups December to January and February to September, indicates possible strong partitioning (allocation of nutrients and moisture) within the tree. The decline of flowering may be a result of partitioning to vegetative growth over the February period. This trend repeated itself in 1999 with a significant high number of flowers between treatment groups December to February and March to September.

Between 16 and 19 months after the first pruning application (December 1998), the resultant regrowth became bearing sites, and had the highest yields. There were three crop cycles between the first pruning treatment application and the yield assessments. The yield assessments conducted at between 27 and 31 months after the first pruning application show less difference in yield between treatments.

The findings that the two-year-old pruning treatments showed little difference in yield among one another indicates that lemons may need to be pruned every year. This is probably due to the vigorous regrowth and prolific bearing habit of this citrus species. Bevington and Bacon (1978) found similar results, in the studies of vegetative response and natural vegetative growth in pruned and unpruned trees. The trees produced natural vegetative growth volume equal to the vegetative response after 2 to 3 years. Vegetative response from pruning depends on several factors including variety, tree age and vigour, fruiting habit, growing conditions, and production practices.

The removal of the number of and type of bearing branches, together with the influence it would have on crop yield, would need to be carefully determined by the pruner. In this study, highest crop value was ascribed to an increase in yield and not fruit size and quality following selective pruning. However, McCarty Boswell, Platt, Opitz and Lewis (1982) found that the removal of foliage from healthy, mature trees reduced yield in direct proportion to the amount of foliage removed, and the pruning of young non-bearing trees delayed fruiting. These findings can not be contested as no control was used in the experimental layout.

The industry trend is to prune *Citrus* from post-harvest to the pre-bloom stage (Bacon and Bevington, 1980). The best time for hedging and topping *Citrus* trees is directly after harvest and preferably before bud burst (Gilfillan, 1991). The findings from this study provide other production advantages to pruning during the summer months, and challenge the practice of pruning only in winter.

The results from this study have important and practical implications. By applying a light pruning on lemons in summer, the vegetative response provides strong bearing units for consequent crop load. The tree concentrates nutrients and moisture into vegetative production when the thermal environment is at its most favourable. These bearing units are an important foundation for future inflorescence and ultimately crop loads.

According to research from the humid Chingking area of West China it was found that summer pruning of orange trees would be a supplementary practice, not a substitute for pruning during the cool periods (Mika, 1986). It is more effective to invigorate neglected and old trees at this time than in the winter. Due to the crop load on the lemon trees, summer pruning can be used to regulate fruit load.

Pruning has an important place in citriculture. The higher density plantings in South Africa have a number of economic advantages, but these advantages have accelerated over-crowding in the orchards. The technology of pruning has been developed to alter trends of vegetative growth and flowering to produce productive and compact canopies producing quality fruit in these changing planting trends. Effective fruit production is the continuous correct application of the right action at the appropriate time. The eventual aim is to have a successful production unit that performs optimally providing a highly profitable undertaking. The volume of fruit exported and the price realisations are critical factors determining the gross income of export-driven citrus growers. The pruning of lemons over summer months will allow for the former by producing the size and quality of fruit the market demands.

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APPENDIX

	Unit	Harvest	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Figure 1	**mm**	**--**	42.93	59.71	52.28	33.95	26.21	17.39	24.08	22.30	27.55	6.54	0.00	0.00
Figure 2	**mm**	**--**	77.49	68.57	89.80	66.07	51.60	43.00	35.19	55.15	44.48	6.27	0.00	0.00
Figure 3	**No.**	**--**	2.03	2.12	1.92	1.47	1.23	1.10	1.11	1.11	1.16	1.13	0.00	0.00
Figure 4	**No.**	**--**	1.26	1.24	1.29	1.39	1.03	0.97	0.83	1.02	0.92	0.99	16.77	16.77
Figure 5	**%**	**--**	49.95	44.15	53.57	46.40	57.21	51.15	57.74	58.19	56.55	53.84	0.00	0.00
Figure 6	**%**	**--**	44.83	47.07	39.90	51.65	40.08	47.99	55.28	52.65	59.84	61.44	0.00	0.00
Figure 7	**°C**	**--**	2288.55	1986.30	1680.95	1343.10	1062.55	828.55	712.30	671.80	633.05	546.25	0.00	0.00
Figure 8	**°C**	**--**	2597.00	2276.15	1911.90	1584.20	1241.65	1003.15	862.10	776.60	686.70	589.05	0.00	0.00
Figure 9	**No.**	**--**	141.00	150.00	50.00	31.00	30.00	22.00	55.00	60.00	42.00	57.00	0.00	0.00
Figure 10	**No.**	**--**	105.00	112.00	72.00	21.00	12.00	6.00	17.00	17.00	15.00	8.00	0.00	0.00
Figure 11	**Ratio**	**--**	1.27	1.24	1.29	1.32	1.28	1.35	1.29	1.28	1.32	1.27	1.28	1.28
Figure 12	**Ratio**	**--**	1.13	1.21	1.17	1.17	1.16	1.15	1.16	1.17	1.18	1.17	1.17	1.17
Figure 13	**%**	**--**	50.71	53.65	54.18	55.71	54.27	55.96	56.99	56.05	56.62	55.88	53.68	53.68
Figure 14	**%**	**--**	61.53	61.93	62.85	61.07	59.12	63.10	62.44	63.39	63.08	61.33	65.23	65.23
Figure 15	**mm**	**--**	4.51	4.42	4.32	4.34	3.92	4.33	4.48	4.35	4.70	4.54	4.39	4.39
Figure 16	**mm**	**--**	5.66	5.46	5.27	5.51	5.67	5.21	5.78	5.78	5.29	6.26	5.79	5.79
Figure 17	**Kg**	**--**	86.84	68.21	53.30	68.70	63.85	58.60	51.48	55.27	57.74	58.93	49.47	49.47
Figure 18	**Kg**	**--**	66.02	58.80	58.11	53.10	43.29	30.82	36.25	32.84	39.21	36.44	36.28	36.28
Figure 19	**Kg**	**--**	77.36	64.60	48.04	67.56	77.36	75.27	63.95	52.58	71.63	63.21	73.63	73.63
Figure 20	**%**	**Harvest one**	59.39	62.86	66.00	72.45	60.25	61.84	57.38	65.37	61.95	48.38	66.10	64.60
Figure 20	**%**	**Harvest two**	40.61	37.14	34.00	27.55	39.75	38.16	42.62	34.63	38.05	51.62	33.90	35.40
Figure 21	**%**	**Harvest one**	46.40	51.62	45.29	53.88	41.12	55.61	37.43	62.12	50.19	51.34	54.11	52.67
Figure 21	**%**	**Harvest two**	53.60	48.38	54.71	46.12	58.88	44.39	62.57	37.88	49.81	48.66	45.89	47.33
Figure 22	**%**	**Harvest one**	41.14	31.27	22.68	33.28	33.56	34.30	39.33	23.89	30.97	27.95	35.42	33.91
Figure 22	**%**	**Harvest two**	58.86	68.73	77.32	66.72	66.44	65.70	60.67	76.11	69.03	72.05	64.58	66.09
Figure 23	**Rand**	**--**		128283			117951			99918			96560	
Figure 24	**Rand**	**--**		106340			67823			62192			62494	

Appendix 1. Data values from graphs presented in this study