EFFECT OF PRUNING ON ECONOMIC BIOMASS PRODUCTION OF PROTEA cv. CARNIVAL

BY

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DECLARATION

I, the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

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SUMMARY

Many *Proteaceae* species indigenous to South Africa have potential as cut-flower crops. Commercial production of proteas for export, mainly to Europe, must emphasise quality of flowers and time of production. Good export quality flowers have stems longer than 50cm and unblemished flowers. Cut-flower proteas are in greater demand and command better prices during the European winter (September to May, Southern hemisphere), when competition from flowers grown in Europe is less. Both quality and time of harvest can be manipulated by pruning techniques.

Protea cv. Carnival (a natural hybrid, possibly between *P. neriifolia* and *P. compacta*) produces flowers in late summer, from February through to May. Picking flowers or pruning shoots of *Protea* cv. Carnival entails removing the terminal portion of shoots with heading cuts to leave on the plant short stumps, known as bearers. Lateral shoots arising from axillary buds on bearers elongate by successive growth flushes until flowers are initiated terminally. The characteristics of the shoot determine whether or not flower initiation will take place, and will affect the quality of the resulting flower. Plants were pruned to produce bearers of different length and diameter. The characteristics of shoots arising from different bearers were recorded. Thick bearers of length 20-25cm produced the most shoots, and the longest shoots. Plants producing flowers biennially, rather than annually, produced thicker bearers, which, in turn, lead to production of better quality shoots arising from the bearers in the following season.

Changing the time of pruning changed both the flowering cycle and the biomass allocation of *Protea* cv. Carnival. Plants of *Protea* cv. Carnival were pruned on six different dates in 1991. Pruning in March, April or May, 1991, resulted in an annual flowering cycle. Less than 40% of the fresh mass produced in 1993 was reproductive, of which approximately 5% had stems long enough for export. The 1994 annual harvest was of similar size and quality as the 1993 annual harvest. Pruning in July, August or September, 1991, resulted in a biennial cycle of flowering. No flowers were produced in 1992, and a large crop was harvested in 1993. In 1993 up to 70% of the

fresh mass produced was reproductive, of which approximately 80% had stems long enough for export. Plants were pruned shortly after flowering in 1993, and the biennial cycle was replaced by an alternate flowering cycle, with a large crop being followed by a smaller crop. The large harvest in 1993 was significantly earlier than normal, but the small crop produced in 1994 was later. The harvest in 1994 from plants with an alternate flowering cycle was similar in size to the 1994 harvest from plants flowering annually, but flower stems were longer.

INVLOED VAN SNOEI OP ECONOMIESE BIOMASSE PRODUKSIE VAN PROTEA CV. CARNIVAL

OPSOMMING

Heelwat inheemse Proteaceae spesies besit die vereiste eienskappe om as snyblomme verhandel te word. Indien proteas kommersieël verbou sou word vir uitvoer moet die klem val op gehalte van blomme en die tyd van produksie. Goeie gehalte uitvoer blomme moet steellengte van langer as 50cm en perfek gevormde blomme besit. Daar is 'n groter aanvraag na kommersieël verboude proteas gedurende die Europese winter (September tot Mei, suidelike halfrond) en beter pryse word derhalwe ook dan verkry. Beide gehalte en die oes periode kan gemanipuleer word deur snoeitegnieke.

Wanneer blomme gepluk word of lote gesnoei word van *Protea* cv. Carnival (waarskynlik 'n kruising tussen *P. compacta* x *P.neriifolia*) word die terminale gedeelte van die loot teruggesny. Die oorblywende gedeelte bestaan uit kort stompe wat bekend staan as draers. Laterale lote afkomstig van okselknoppe op draers verleng totdat 'n blom terminaal ontwikkel. Die eienskappe van die loot bepaal of 'n blom inisieer sal word of nie, en sal ook die gehalte van die gevormde blom beinvloed.

Protea plante was gesnoei om draers van verskillende lengtes en deursnee te produseer. Die eienskappe van lote afkomstig van die verskillende tipe draers was gemeet. Dik draers van lengte 20-25cm het die meeste asook die langste lote geproduseer. Plante wat twee-jaarliks, in teenstelling met jaarliks, geblom het, het dikker draers geproduseer en ook gelei tot produksie van beter gehalte lote in die opeenvolgende seisoen.

Die verandering in die tyd van snoei het beide die blom siklus en die biomassa verspreiding beinvloed. Plante van *Protea* cv. Carnival was op 6 verskillende datums in 1991 gesnoei. Snoei in Maart, April of Mei, 1991, het 'n jaarlikse blom siklus veroorsaak. Minder as 40% van die vars massa geproduseer in 1993 was reproduktief, waarvan 5% steellengte lank genoeg vir uitvoer gehad het. Die 1994 jaarlikse oes was van dieselfde grootte en gehalte as dié van 1993. Snoei in Julie, Augustus of September, 1991, het egter 'n twee-jaarlikse blom siklus veroorsaak. Geen blomme was in 1992 geproduseer nie, maar die oes in 1993 was heelwat groter as die jaarlikse

oeste. In 1993 was to 70% van die vars massa geproduseer, reproduktief, waarvan 80% steellengte lank genoeg vir uitvoer gehad het. Die twee-jaarlikse blom siklus het 'n vroeër oes in 1993 veroorsaak, maar 'n later oes in 1994. Die twee-jaarlikse oes in 1994 was van dieselfde grootte as die jaarlikse oes in 1994, maar die blomstele was langer.

CONTENTS

1. INTRODUCTION

There are many *Proteaceae* species indigenous to South Africa which have potential as cut-flower crops. At present many flowers are picked from plants in naturally established stands. These flowers are not of high enough quality for export and there is a need for production of high quality cultivated flowers.

Commercial production of proteas in South Africa for export, mainly to Europe, must emphasise quality of flowers and time of production. Good export quality flowers have stems longer than 50cm and unblemished flowers and foliage. Cut-flower proteas are in greater demand and command better prices during the European winter (September to May, Southern hemisphere), when competition from flowers grown in Europe is less. Both quality and time of harvest can be manipulated by pruning techniques. Correct pruning can increase the yield and the productive lifespan of the plant. Pruning also serves to limit and maintain a manageable plant size and shape (Brits, Jacobs & Steenkamp, 1986).

Current practice in commercial plantations of *Protea* cv. Carnival (a natural hybrid, possibly between *P. neriifolia* and *P. compacta*) is to prune plants shortly after harvest, generally toward the end of April. Pruning entails heading both flowering and non-flowering shoots to leave short stumps, known as bearers. Lateral shoots arising from the bearers elongate by successive growth flushes until a flower is initiated terminally. The factors affecting flower initiation in *Protea* cv. Carnival are not understood, but the length and diameter of shoots is thought to play a role (De Swardt, 1989). The number and quality of shoots on a plant specify the potential crop for the following season. For annual flower production shoot growth and flower initiation must take place in the same year. This results in low yields of short-stemmed flowers.

Bearers can vary in length and diameter and are generally thinned out to leave 2.5 bearers per centimetre trunk circumference, as measured 10cm above ground level. The thinning out process must retain bearers which will give the most vigorous growth response, and remove weak bearers. Current pruning practise is to remove thin, spindly shoots and head all other shoots to leave bearers of approximately 15cm. Often shorter bearers are left when flowers are picked to maximise stem length. This could result in weak regrowth if the bearers are thin.

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2. LITERATURE REVIEW - Vegetative response to pruning

Vegetative response to pruning

1. Introduction.

Pruning is the physical manipulation of plants in order to change the developmental pattern. This has the effect of changing or specifying the shape (or architecture) and size of the plant, and influences the vegetative/ reproductive development. All these effects are the net result of altering physiological balances such as changes in hormone levels, energy supplies, nutrient assimilation, and water relations within the plant (Stiles, 1984).

The response of a plant to pruning can be measured by a number of different criteria. Many experiments quantify a pruning response by its effect on the reproductive development in terms of flowers or fruit. The vegetative response to pruning is measured by noting the number and position of buds breaking as a result of the pruning cut, and the vigour of subsequent shoot growth. Axillary bud break is controlled by correlative inhibition attributed to apical dominance. Zieslin & Halevy (1976) found that, in roses, both the stem section above a bud and the leaf subtending the bud played a role in this correlative inhibition. Growth of lateral shoots following bud break is under the influence of apical control (Suzuki, Kitano & Kohno, 1988). Apical dominance can be broken by the cessation of growth of the apical meristem. Removal of the terminal portion of the shoot by pruning also releases lateral buds from apical dominance. Despite this release not all lateral buds break and form shoots. Effects on the tree as a whole such as canopy spread and tree height are direct effects of differences in shoot number, position and length. Changes in trunk cross sectional area and root mass are indirect effects, probably due to changes in assimilate distribution (Scorza, Zailong, Lightner & Gilreath, 1986).

2. Factors affecting pruning response.

2.1 Type of pruning cut.

There are many different descriptions of types of pruning cuts in the literature (Barden, Delvalle & Myers, 1989; Lord & Damon, 1983; Martin, 1989; Peterson, 1992; Saunders, Jacobs & Strydom, 1991; and Zai-long, 1984). They all agree on two types of pruning cuts. These are the heading or heading-back cut, defined as the removal of a terminal portion of the shoot, and the thinning or thinning-out cut, defined as the removal of an entire shoot at its junction with a lateral or scaffold branch or with the trunk.

The severity of a heading cut depends on how much of the shoot is removed. Peterson (1992) distinguishes between a heading cut into one-year-old wood and a cut into two-year-old and older wood (called stubbing by Lord & Damon (1983), and shortening-back by Zai-long (1984)), since they result in different growth responses. Saunders *et al.* (1991) define a third type of cut, called topping, by which the upper half of the one-year-old shoot portion is removed. Research on mulberry trees refers to removal of a terminal section of a shoot simply as decapitation (Suzuki *et al.*, 1988).

Different pruning cuts elicit different growth responses, and hence are used for different, yet specific purposes. The stimulation of shoot growth is most pronounced when heading cuts are made on one-year-old wood. Very vigorous shoots develop from the three or four buds immediately below the cut due to loss of apical dominance. Crotch angles subtended by these shoots tend to be narrow. Heading into older wood is not as invigorating and is used to change the direction of growth, and improve light distribution into the tree canopy. The thinning cut does not increase shoot growth as much as heading and is used to open up the tree canopy to alleviate crowding and shading (Peterson, 1992).

2.2 Time of pruning.

The response to a specific cut is influenced by the time at which the cut is made. The time is generally reported as a time of year, which corresponds to a specific phenological stage of growth. Prevailing environmental conditions also have an effect.

Oosthuyse, Jacobs & Strydom (1992) studied the effect of time of heading relative to full-bloom in one-year-old "Granny Smith" apple shoots. Their results show that both number of buds sprouting, and total length of new shoots formed were influenced. At all heading dates the number of buds which remained dormant was greater than the number of buds which grew. The maximum number of buds broke when shoots were headed 14 days after full- bloom. Fewer buds broke when branches were headed earlier (up to 70 days before full-bloom) or later (up to 28 days after full-bloom). The same trend was shown by total length of new shoots, although the maximum total length was achieved by heading 28 to 56 days before full bloom. At these dates the fewest buds broke and competition between buds was probably reduced (Oosthuyse *et al.*, 1992).

The vegetative response of mulberry shoots to decapitation was correlated with change of season (Suzuki *et al.*, 1988). When shoots were decapitated in mid- summer (June 1, Nortnern hemisphere) 16% of lateral buds per shoot sprouted. There was a decline as summer progressed, and in autumn (September .0, Northern hemisphere) only 2% sprouted. The final length of new shoots also declined over the same period, from 161cm to 30 cm.

The most obvious distinction with regard to time of pruning is between "dormant" and "summer" pruning. These terms refer to deciduous trees which undergo a period of dormancy during winter. The time of pruning during winter is not critical, and is usually done shortly after leaf-fall (Wertheim, 1976). Evergreen plants do not have a dormant period and, although growth is sometimes less active, leaves are always present to produce photosynthates. This is relevant to pruning in two main ways (McCarty & Lewis, 1964). Firstly bud break and initial shoot growth are not necessarily dependant on reserves stored in the wood and roots. Secondly, pruning not only removes woody tissues (which may or may not contain reserves), but also removes leaves responsible for photosynthesis. Pruning of evergreen plants is probably more comparable with summer pruning of deciduous plants, although the physiological stage of growth at the time of pruning will determine the response.

3. Severity of pruning.

The severity of pruning is dependant on the amount of plant matter removed, and the plant responds differently to different severities of pruning. When a shoot is pruned the buds near the cut break and form side-shoots. The vigour of the side-shoots and the crotch angle formed depend on the severity of pruning.

The earliest experiments reporting the response of apple trees to different severities of heading cuts were done by Koopmann in 1896 (see Jonkers, 1982, and Wertheim, 1976). Not all of Koopmann's rules were confirmed by the work of Jonkers (1982), and many were found to be cultivar dependant, but many generalisations were summarised by Wertheim (1976).

-The more severe the heading, the more vigorous side-shoot growth is, unless the shoot is cut back to a position where only adventitious buds occur.

-The total length of the shoot plus all side-shoots is the same when the shoot is lightly pruned , but not when pruning is severe.

-The total growth of all side-shoots combined is constant, unless more than 60% of the shoot is removed, in which case total growth is reduced. This trend of total side-shoot growth also applies to increase in mother-shoot diameter and number of leaves. The average leaf size, however, increases with increasing severity of pruning, provided that no more than 30% of the shoot is removed.

-With an increase in severity of pruning the length of side-shoot per bud breaking increases, and the total number of side-shoots, particularly short shoots, decreases. To explain the increase in shoot vigour with increase in pruning severity Wertheim (1976) postulated that the supply of growth factors to the buds is critical. Pruning reduces the number of buds on a shoot. The available supply of growth factors is shared between fewer buds, which results in increased vigour.

The growth response of the axillary buds on a shoot to pruning is dependant also on the shoot's position and orientation relative to other shoots (Wertheim, 1976).

-Two shoots will show a similar response to pruning if they are of the same length and diameter, and are at the same position on, and the same angle to, a branch.

-If their crotch angles differ, the most vertical shoot will show the most vigorous response.

-If their crotch angles are the same, but they arise at different positions on the branch, the most distal shoot responds more vigorously.

-The thickest shoot grows more vigorously, if all other shoot characteristics are the same. This also applies to the shoot closest to the main stem.

-If a shoot is bent to the horizontal position the uppermost buds show the most vigorous response.

Using these principles it is possible to assess relative vigour of shoots within a whole tree (Wertheim, 1976).

Unpruned branches and trees form more short shoots, and fewer long shoots, than when severe pruning is applied. Flower initiation occurs mainly on short shoots, in apple.

and little or no pruning leads to precocious flowering, which, depending on the extent of the June drop of fruit, leads to earlier bearing. Early bearing leads to a decrease in root and shoot growth which limits growth of the tree as a whole. Although not pruning leads to earlier production, pruning is essential for renewal of bearing wood (Wertheim, 1976).

Maggs (1959) also studied the partitioning of growth between various plant parts as a result of pruning severity. Three degrees of severity were applied to rooted shoots of different diameter apple rootstock. These were; (a) removal of 5cm of the tip, (b) half the length removed, and (c) two- thirds of the length removed. The number of buds breaking was highest with tip pruning, although many of these failed to elongate, and remained as spurs. The mass of each plant part was expressed as a percentage of the total increase in mass of each plant. In agreement with Jonker's results (1982), the mass of new stem produced increased with pruning severity. However, the increase in the mass of the old stem correspondingly decreased. Thus, the percentage of the total increase in mass following pruning, that was due to the mass of new stem plus old stem, remained constant, despite different severities of pruning, as was stated by Wertheim (1976).

Stiles (1984) questioned the extrapolation of results from pruning studies of single stemmed trees to older trees with complex branch systems. As well as the influence of rootstocks on the rate of aging of a tree, there are also interactions between vegetative and reproductive growth.

Five-year-old apple trees (cv. Red Prince Delicious) were used to investigate the responses to heading cuts made into dormant one-year-old wood and two-year-old wood (Barden *et al.*, 1989). Cuts were made at (a) the mid-point of the one-year-old shoot portion, (b) at the junction between one- and two-year-old wood, and (c) at the mid-point of the two-year-old shoot portion. Compared to an unpruned control, shoot number decreased and mean shoot length increased in all pruning treatments. The response was the greatest when the cut was made at the mid-point of two-year-old wood (i.e. the most severe), but the other two treatments did not differ from each other in their response. Total shoot growth, as a function of shoot number and shoot length, was decreased relative to the control only in the most severe pruning treatment (Barden *et al.*, 1989).

Elfving & Forshey (1976) also studied the effect of increased pruning severity on mature, dormant, apple trees (cv. Delicious). Cuts were made at various points along one-year-old shoot portions. The removal of a greater portion of one-year-old wood resulted in increased shoot growth from both one- and two-year-old wood below the cut. The increased shoot growth originating from one-year-old wood was a direct result of an increase in shoot elongation with no change in number of shoots. The increase on two-year-old wood, however, was a function of increased shoot numbers (Elfving & Forshey, 1976). These experiments differed from those of Barden *et al.* (1989) in both the degree of severity of pruning and experimental design. On one tree Barden *et al.* (1989) selected seven similar branches which received one of the pruning treatments each. Each pruning treatment done by Elfving & Forshey (1976) was applied to every branch of an entire tree. The different results obtained emphasise the role of competing sinks.

Feree & Lasko (1979) investigated severity of pruning as a function of frequency of pruning. The same pruning strategy was carried out on different trees annually, biennially or triennially. Measurements of tree height, canopy spread and trunk circumference were recorded once a year. Over a six year period the six cultivars tested responded similarly to the pruning treatments. There were no apparent differences in trunk circumference, tree height or in-row spread of trees. Pruning annually did, however, result in a larger yield/trunk cross sectional area (Feree & Lasko, 1979).

3. Summary

The response to pruning is modified by environmental conditions and genetic factors within the plant. As well as the factors already discussed, many responses to pruning are rootstock (Young & Werner, 1984) and cultivar (Kaini, Jackson, & Rowe, 1984) dependant. Development of new genetic stock will necessitate a re-evaluation of pruning strategies. The same is true for innovations in orchard management systems (Clayton-Greene, 1993). Already adjustments have been made to allow for increased planting density (Fochessati, 1982). Mechanical pruning has received attention as a means of reducing labour costs of pruning, and is already widely used on citrus (Lewis & McCarty, 1973).

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PAPER I - Effect of time of pruning on flowering cycle of *Protea* cv. Carnival.

Effect of time of pruning on flowering cycle of *Protea* cv. Carnival.

Abstract. **Plants of *Protea* cv. Carnival were pruned on six different dates in 1991. The 1993 and 1994 yields were analysed in terms of vegetative, reproductive and economic biomasses. The pruning date influenced biomass allocation, and determined whether flowers were produced annually or biennially. Pruning in March, April or May, 1991, resulted in an annual flowering cycle, with less than 40% of the fresh mass produced annually being reproductive. The 1994 annual harvest was of similar size and quality to the 1993 annual harvest. Pruning in July, August or September, 1991, resulted in no crop being produced in 1992, but a large crop in 1993, with up to 70% reproductive biomass being produced. Plants flowering biennially were pruned after harvest in March, 1993, and the flowering cycle became alternate, rather than biennial. The biennial, or alternate, flowering cycle resulted in an earlier harvest in 1993, but a later harvest in 1994. The 1994 alternate harvest was similar in size to the 1994 annual harvest, but flower stems were longer.**

INTRODUCTION

Proteas grown for export to the European cut flower market must be cultivated with emphasis on quality and time of production. Cut flower proteas are in greater demand and command better prices from September to May. During the remaining months (European summer), there is great competition from cut flowers grown in Europe, thus reducing demand for imported flowers. Further, profit is decreased by higher import surcharges imposed on cut flowers imported during the European summer. Competition between commercial protea growers results in high prices being paid only for best quality blooms, even during times of high demand.

Pruning of proteas releases axillary buds from apical dominance, resulting in growth of shoots which elongate by successive growth flushes. Elongation stops when flower initiation occurs terminally. *Protea* cv. Carnival (a natural hybrid, possibly between *P. neriifolia* and *P. compacta*) can produce an autumn flush, starting in April/May, a spring flush, starting in August/September, and two summer flushes, the first beginning in December, and the second in February to April (Greenfield, Jacobs & Theron, 1994). According to Dupee and Goodwin (1990) flower initiation in *P. neriifolia* occurs after growth of the spring flush is complete. However, Greenfield *et al.* (1994) found that shoots of *Protea* cv. Carnival initiated flowers terminally on the spring or first summer growth flushes. Fifty percent of the flowers were initiated on spring flushes, at which stage stems generally consisted of only two growth flushes (autumn and spring). Current commercial pruning practices aim at producing both shoots and flowers within twelve months. This results in low yields of short-stemmed flowers. In this paper we report on yield and flower quality as affected by pruning practices which result in shoot growth in one year and flower initiation the following year

MATERIALS AND METHODS

Experiment 1

Six-year-old plants of *Protea* cv. Carnival grown commercially under natural climatic conditions near Stellenbosch, Cape Province, South Africa (33° 54'S) were used. The area receives an annual winter rainfall of 600- 700mm. Plants were spaced one metre apart in the row and four metres between rows and were not irrigated or fertilized. In 1991 plants were pruned on six different dates, namely, 12 March, 9 April, 21 May, 2 July, 13 August, and 17 September. Plants pruned on the first three dates (referred to as 'early pruning') flowered the following season (1992), and were pruned again on 24 April, 1992, when harvesting was complete. Plants pruned on the last three dates (referred to as 'late pruning') failed to flower in 1992 and were not pruned in 1992.

Pruning entailed heading both flowering and non-flowering shoots, leaving a 15cm portion of the stem to serve as a bearer for the following year's growth. Spindly shoots were removed by thinning cuts. In 1991 the number of bearers per plant was reduced using thinning cuts to leave 2.5 bearers per centimetre trunk circumference, as measured 10cm above ground level. In following years the number of bearers was not specified and counted, but spindly growth was thinned out, as is done in commercial practice.

Flowers produced in 1992 and 1993 were harvested when commercially mature. In 1992 flowers were harvested for maximum stem length, as done commercially, either leaving a short bearer or with a thinning cut. In 1993 flowers were harvested leaving a 15cm bearer, regardless of the length of the stem. Once harvesting was complete plants were pruned as described above. Flowering and non-flowering shoots were weighed to determine reproductive and vegetative biomass respectively. Shoots that developed below a flowerhead were cut off and included in the vegetative biomass. Flowering stems were classified according to stem length and quality. Stems shorter than 50cm were classified as non-exportable. Percentage reproductive biomass was calculated as the percentage of the total biomass that consisted of flowering shoots, without taking flower and stem quality into account.

Single plants were used per treatment, replicated ten times in a randomised complete block design. Data was analysed using the General Linear Means (GLM) procedure of Statistical Analysis System (SAS) (SAS Institute Inc., 1990).

Experiment 2

The different pruning treatments described in Experiment 1 resulted in plants with different flowering cycles. Those plants pruned early in 1991 retained the annual flowering cycle. Pruning late in 1991 forced the plants into a biennial flowering cycle, where a large crop was produced in the second year after pruning (1993). After harvest in 1993, plants were again pruned. Biennial-flowering plants were pruned in mid-March, and annual-flowering plants at the end of April. All plants produced flowers in 1994. The 1994 harvest from ten annual-flowering plants and ten biennial-flowering plants was picked and analysed for size, time and quality of yield. Flowers were picked using thinning cuts. This was done to maximise stem length and to prevent any new shoots being produced. Lateral shoots would be shaded by, and compete with vegetative shoots remaining on the plant. The plants were not pruned in 1994 after harvest, hence vegetative and total biomass could not be measured.

Single plants were used per treatment, replicated ten times in a randomised complete block design. Data was analysed using the GLM procedure of SAS (SAS Institute Inc., 1990).

RESULTS

Experiment 1

The time of pruning dictates whether the plant produces both shoots and flowers within twelve months, or produces shoots only in the first growing season followed by flower production the next. Plants which were pruned early in 1991 and again in 1992 produced both shoots and flowers within a year. Flowers were produced annually in 1992 and 1993. Plants pruned late in 1991, and not pruned in 1992, produced shoots only during the 1991/1992 growing season (Greenfield *et al.*, 1994), and flowers during the following season (1992/1993). This shows a trend towards biennial flower production.

Fresh biomass production

Plants flowering biennially produced significantly more total, reproductive, and percentage reproductive biomass in 1993 than plants flowering annually (Table 1). The only carry-over effect of the 1991 pruning on the 1993 harvest (with regard to early-pruned plants) was in the percentage reproductive biomass, where plants pruned in May 1991, had a higher percentage than plants which were pruned earlier (March or April).

Yield and flower quality

Plants which were not pruned in 1992 (biennial flowering) produced significantly more flowers in 1993 than plants which were pruned in 1992 (annual flowering) (Table 2). Of the plants flowering biennially those pruned in September 1991 produced the most flowers. The majority of the flowers produced in 1993 by plants flowering annually had stems shorter than 50cm. In contrast, more than 70% of flowers produced biennially in 1993 had stems longer than 50cm (Table 2).

Plants flowering biennially produced more flowers in 1993 than the combined 1992/1993 harvest from plants which flowered in both years (Table 3). Thus over a two year period plants pruned in July, August or September 1991, produced more flowers than plants pruned in March, April or May 1991, and again in April 1992. Delaying pruning until late 1991 changed the harvest from flowers produced annually with short stems (less than 50cm) to flowers produced biennially with long stems (longer than 50cm).

Time of harvest

The time of harvest in 1993 was affected by the date of pruning in 1991 (Table 4). Plants flowering annually produced the most flowers in April, 1993, with less than 40% being picked in March, 1993, and only a small percentage in February, 1993. The biennial harvest in 1993 was early, with approximately 60% of the harvest being picked in February, 1993. Harvesting began in January, 1993, and continued until 12 March, 1993, when the plants were finally pruned.

Experiment 2

A comparison between the annual harvests of 1993 and 1994 showed no significant difference with respect to total yield (data not shown). This indicates that annual climatic fluctuations did not significantly affect yield. Plants which did not flower in 1992 but produced a large crop in 1993 (biennial-flowering), also produced flowers in 1994. These plants are essentially no longer biennial-flowering, but alternate-flowering, with a large crop preceding a small crop.

Yield and flower quality

In 1994 annual-flowering plants and alternate-flowering plants produced the same number of flowers per plant (Table 5). The majority of the flowers produced in 1994 (by plants of either flowering cycle) had stems of between 30 and 50cm long, although the mean stem length of flowers born on alternate-flowering plants was significantly longer than that of annual-flowering plants. In contrast to the 1993 harvest, where more than 70% of the flowers produced by biennial-flowering plants had stems longer than 50cm, only 35% of the 1994 alternate harvest had long stems. This percentage was still significantly higher than that of annual- flowering plants.

Time of harvest

Flowers were harvested in 1994 from plants of both flowering cycles from February to April, 1994. Most of the crop from annual-flowering plants was harvested in March, 1994 (Table 6), with 20% being harvested in April, 1994, and less than 10% in February, 1994. The harvest from alternate- flowering plants was spread more evenly over the three months, although almost 50% of the flowers produced were picked in April, 1994.

CONCLUSIONS

With present pruning practices *Protea* cv. Carnival has an annual flowering cycle. Stems elongate following budbreak shortly after pruning until late spring or early summer when flower initiation takes place. Two to three flushes are produced during this 8 to 9 month growing period. By changing the time of pruning the cycle can be adjusted to a biennial one. The advantage of biennial flowering over annual flowering in terms of time, size and quality of harvest is due solely to the fact that flower initiation does not take place in the first year of the biennial cycle.

It is not known what factor(s) control flower initiation in *Protea* cv. Carnival. Flower initiation is induced by short days in *Leucospermum* cv. Red Sunset (Malan & Jacobs, 1990) and *Serruria florida* (Malan & Brits, 1990). De Swardt (1989) found that no shoot growth or reproductive development occurred in *Protea* cv. Ivy under short day conditions, although shoot growth continued in winter when long days were simulated with artificial lighting (unpublished data). It is unlikely that flower initiation in *Protea* cv. Carnival is affected solely by daylength since flowers can be initiated on the first summer flush, produced in mid-summer (December), but not the second summer flush, produced in late summer.

De Swardt (1989) found that the length and thickness of stems of *Protea* cvs. Ivy and Carnival significantly contributed to the ability of the stem to produce a flower, although this was not the only factor involved. Longer, thicker stems were more likely to produce flowers than short, thin stems. Greenfield *et al.* (1994) suggested that, in pruned plants, at least two flushes of shoot growth are needed before flower initiation will occur in *Protea* cv. Carnival. In the first year of the biennial cycle shoots had elongated by only one or two growth flushes at the time at which flower initiation normally takes place. These shoots were probably below a critical stem length or diameter necessary for flower initiation. Shoot elongation continued into the second year of the biennial cycle when flowers were initiated, by which time stems were long enough for export. Stem diameter also plays a role in flower quality- an increase in diameter leading to an increase in flowerhead dry mass (Napier *et al.*, 1986), flowerhead diameter and number of styles (Jacobs & Minnaar, 1980; Jacobs, 1983).

Greenfield *et al.* (1994) found that in an annual cycle low yields of *Protea* cv. Carnival were not due to a shortage of shoots. Many of the shoots probably did not have the stem length or diameter characteristics supposed to be necessary for flower initiation (De Swardt, 1989). In the biennial cycle these shoots are allowed a further growing season to lengthen and thicken and produce flowers. This explains the difference in percentage reproductive biomass between plants flowering annually and biennially while the total biomass produced did not vary.

Biennial flowering, often termed alternate bearing, is a widely occurring phenomenon found in both deciduous and evergreen trees. An alternate bearing tree does not produce evenly sized crops year after year. A heavy yield in the "on-year" is followed by a light yield, or no yield in the "off-year".

In the first "off-year" (1992) biennial-flowering plants of *Protea* cv Carnival produced no flowers. The crop in the "on-year" (1993) was better than two normal annual crops, in terms of number and quality of flowers. Shoots produced by plants flowering biennially were long and thick in spring of the second year. Flowers were initiated on the spring flush and matured early. The 1994 harvest was the second "off-year". Instead of being a very poor harvest, as would be expected from alternate bearing plants, it was the same as a normal annual crop in terms of number of flowers produced, and was better in terms of flower quality. Biennial-flowering plants were pruned in 1993 about six weeks earlier than annual- bearing plants. The extra growing time should have reflected in an earlier harvest, but this was not the case. Although, at the beginning of summer in 1993, (when flower initiation normally takes place) vegetative shoots from biennial (or alternate)-flowering plants had the minimum of two growth flushes proposed to be essential for flower initiation by Greenfield *et al.* (1994), the mean combined length of these two flushes was only 34cm. A third flush (first summer) was necessary for flower initiation. The mean combined length of the first two flushes of stems on annual-bearing plants was 43cm, and flowers were initiated earlier. Whether the stem length is the critical factor or the number of leaves producing photosynthates limits the stems potential to initiate flowers still needs to be clarified.

Flower production in an alternate-flowering cycle improves both yield and flower quality. Flowers produced in the "on-year" are mature for harvesting early in the year when demand is high. The improved harvest in the "on-year" in terms of time, numbers, and quality of flowers more than compensates for cropping only every second year, and the "off-year" is no worse than the annual harvest.

From a practical point of view, to pick in March and prune in September, after partial regrowth, increases farm labour requirements, and could deplete the plant's resources if done regularly. The vegetative shoots remaining on the plant after picking in 1994 (the "off-year") should initiate flowers and produce a large crop in 1995 (the "on-year"). Then, the practical management of biennial, or alternate, flowering would entail pruning the plants after harvest in the "on-year", and picking flowers in the "off-year" using thinning cuts. Harvests would alternate between extremely good and normal annual harvests.

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Table 1:- Effect of pruning date on fresh biomass production of *Protea* cv. Carnival - 1993 harvest

	Pruning date 1991	1992	Total Mass (g)	Reprod Mass (g)	Veget Mass (g)	%Reprod Mass
Annual	12 March	24 April	7915	2[illegible]	5772	25
	9 April	24 April	6276	1[illegible]	5025	19
	21 May	24 April	7900	3162	4738	40
	Mean		7364	2186	5178	28
Biennial	2 July	none	12531	8195	4336	66
	13 August	none	12557	8772	3785	71
	17 Sept	none	14432	10110	4322	70
	Mean		13173	9025	4148	69

ANOVA

Source		Significance		
Annual vs Biennial	0.0001	0.0001	0.0339	0.0001

Table 2:- Effect of pruning date on flower quality of *Protea* cv. Carnival - 1993 harvest

	Pruning date		Number	Percentage of total		
	1991	1992	stems	>50 cm	30-50cm	<30cm
Annual	12 March	24 April	15	4.7	78.3	16.6
	9 April	24 April	11	6.0	82.4	11.1
	21 May	24 April	26	3.8	86.6	8.3
	Mean		17.3	4.8	82.4	12.0
Biennial	2 July	none	45	74.2	10.7	0.0
	13 August	none	56	79.6	12.6	0.6
	17 Sept	none	63	85.8	8.2	0.1
	Mean		54.7	79.8	10.5	0.2

ANOVA

Source	Significance
Annual vs Biennial	0.0001

Table 3:- Effect of pruning date on number of *Protea* cv. Carnival flowers produced.

Flowering cycle	Pruning date 1991	1992	Mean number of flowers/plant 1992*	1993	1992+1993
Annual	Early	24 April	13	17.3	30.3
Biennial	Late	none	0	54.7	54.7

* Data from Greenfield *et al.* (1994)

Table 4:- Effect of pruning date on time of harvest of *Protea* cv. Carnival - 1993 harvest.

	Pruning date 1991	1992	January %	February %	March %	April %
Annual	12 March	24 April	0	3.84	38.44	57.75
	9 April	24 April	0	3.65	36.86	59.48
	21 May	24 April	0	3.41	36.12	60.46
	Mean		0	3.63	37.14	59.23
Biennial	2 July	none	3.55	60.11	36.35	0
	13 August	none	0.61	58.85	40.54	0
	17 Sept	none	1.94	63.05	35.00	0
	Mean		2.03	60.67	37.30	0

Table 5:- Effect of flowering cycle on flower quality of *Protea* cv. Carnival - 1994 harvest.

Flowering cycle	Total flowers	Number of flower stems (% of total) >50cm	30-50cm	<30cm	Mean length (cm)
Annual	11.4	0.3 (3.75)	9.6 (85.02)	1.4 (11.22)	**35.8**
Biennial	11.8	4.6 (35.41)	6.6 (60.11)	0.6 (4.47)	**46.4**

ANOVA

Source			Significance		
Annual vs Biennial	0.8862	0.0031	0.1185	0.2353	0.0001

Table 6:- Effect of flowering cycle on time of harvest of *Protea* cv. Carnival - **1994 harvest.**

Flowering cycle	Total flowers	Number of flower stems (% of total) February	March	April
Annual	11.4	0.8 (7.12)	8.7 (72.40)	1.9 (20.48)
Biennial	11.8	1.0 (13.27)	5.2 (37.82)	5.6 (48.91)

ANOVA

Source			Significance	
Annual vs Biennial	0.8862	0.7263	0.1594	0.0025

PAPER II - Effect of bearer characteristics on shoot growth of *Protea* cv. Carnival.

Effect of bearer characteristics on shoot growth of *Protea* cv. Carnival.

Abstract. **Picking flowers or pruning shoots of *Protea* cv. Carnival entails removing the terminal portion of shoots with heading cuts. This leaves short stumps on the plant, known as bearers. Lateral shoots arising from axillary buds on bearers elongate by successive growth flushes until flowers are initiated terminally. The characteristics of the shoot determine whether or not flower initiation will take place, and will affect the quality of the resulting flower. Plants were pruned to produce bearers of different length and diameter. The characteristics of shoots arising from different bearers were recorded. Thick bearers of length 20-25cm (consisting of one growth flush) produced the most shoots, and the longest shoots. Plants pruned to have a biennial flowering cycle produced thicker bearers, which, in turn, lead to production of better quality shoots arising from these bearers in the following season.**

INTRODUCTION

Proteas are grown commercially in South Africa for export, mainly to Europe. The success of the farming venture depends on the number and quality of flowers harvested. Good export quality flowers have straight stems longer than 50cm and unblemished flowers and foliage. Yield per hectare is determined by the planting density and the number of flowers produced per plant. The size of the plant and the type of implements used specify the plant spacing. Cultivation practises, particularly pruning, affect the yield per plant (Paper I).

Current practise in commercial plantations of *Protea* cv. Carnival is to pick the market-ready flowers leaving behind on the plant short stumps, known as bearers. Once all the flowers have been picked the plants are pruned. Pruning entails removing non-flowering shoots with a heading cut to leave bearers. Picking the flower, which is borne terminally, and heading non-flowering shoots, releases lateral buds on the bearer from apical dominance. New shoots elongate by successive growth flushes until a flower is initiated terminally. The number of shoots arising from each bearer and the number of bearers per plant specifies the potential crop for the following season. The factors affecting flower initiation in *Protea* cv. Carnival are not yet understood, but shoot characteristics are thought to play a role. De Swardt (1989) found that the length and thickness of stems of *Protea* cvs. Ivy and Carnival significantly contributed to the ability of the stem to flower. Greenfield, Theron & Jacobs (1994) found that vegetative shoots of *Protea* cv. Carnival initiated flowers in late spring or early summer. Only shoots which have grown sufficiently since pruning will be long enough and/or thick enough to initiate flowers. Sedgley & Fuss (1992) found that in two Banksia species the likelihood of a shoot producing a flower was correlated with shoot age and size.

Plants of *Protea* cv. Carnival produce flowers annually if pruned directly after flowering in March or April. Vegetative shoots grow for 8 to 9 months until flower initiation can occur in early summer. If pruning is delayed until early spring (August or September) the plants do not flower in the following year, but enter into a biennial cycle of flowering, during which vegetative shoot growth continues for 12 to 16 months before flower initiation. The different patterns of shoot growth on plants with different flowering cycles could affect the characteristics of bearers produced by pruning.

This paper reports on the effect of bearer quality on the number and quality of shoots produced. The number of bearers remaining on a plant after picking and pruning did not affect the total number of flowers produced by the plant (Greenfield, Theron & Jacobs, 1994). The correct practise is to leave bearers of length 15-20cm, but shorter bearers are often left in an attempt to maximise the stem length of the harvested flower. The characteristics of shoots arising from bearers of different length and diameter were measured in an attempt to quantify bearer dimensions which will result in optimal flower production.

MATERIALS AND METHOD

Experiment 1

Four-year-old plants of *Protea* cv. Carnival grown commercially under natural climatic conditions were used. The area, near Stellenbosch, Cape Province, South Africa (33° 54'), receives an annual winter rainfall of 600- 700mm. Plants were spaced one metre apart in the row and four metres between rows and were not irrigated or fertilized. The four pruning treatments applied entailed heading both flowering and non-flowering shoots to leave different length bearers. Spindly shoots were removed with thinning cuts. The number of bearers per plant was reduced using thinning cuts to leave 2.5 bearers per centimetre trunk circumference, as measured 10cm above ground level. All the bearers on a single plant were pruned to the same length. The lengths chosen were relative to the growth of the stem rather than absolute, measured lengths. The longest bearers (31-35cm) consisted of the entire first flush arising from the branch plus half of the next flush on the stem (1+½). The second longest bearers (20-25cm) consisted of the entire first flush only, through heading back to the intercalation between the first and second flushes on the stem (1). The two other lengths of bearer consisted of one half of the first flush (½) (12-16cm), and one quarter of the first flush (¼) (7-9cm) arising from the branch. All plants were pruned between 21 and 24 April, 1993. Ten bearers per plant were selected from the top of the bush. Five of these bearers had a tip diameter of less than 8mm, measured with calipers, and were labelled "thin". The other five bearers selected had a tip diameter greater than 8mm and were labelled "thick".

At the end of February, 1994, all ten bearers per plant were picked with a thinning cut and taken to the laboratory for analysis. The number of shoots per bearer, the length of each shoot and the number of flushes per shoot were recorded. The number of vegetative shoots longer than 40cm was taken as an indication of the potential flower crop in 1995 These shoots should produce one or two more growth flushes before flower initiation, which will ensure that the stems are the minimum exportable length of 50cm.

Single plants were used per treatment, replicated seven times in a randomised complete block using a split- plot design, with bearer length as the main treatment and bearer diameter as the sub- treatment. Data was analysed using the General Linear Means (GLM) procedure of Statistical Analysis System (SAS) (SAS Institute Inc., 1990).

Experiment 2

Six-year-old plants of *Protea* cv. Carnival grown under the same conditions as described above were used. Plants were either pruned early in 1991 (March, April or May) to produce flowers annually, or were pruned late in 1991 (July, August or September) to force the biennial flowering cycle (see Paper 1). Annual flowering plants were pruned again in April, 1992, after flowering.

In 1993 both biennial- and annual-flowering plants were pruned after flowering. Biennial-flowering plants were pruned in mid-March, and annual-flowering plants were pruned at the end of April. All shoots were pruned to leave a bearer of length 15-20cm. Spindly shoots were removed with thinning cuts.

Ten bearers per plant were randomly selected from the top of the plant and labelled. Bearers on the sides of the plants were ignored to eliminate factors such as shading or mechanical damage. When extension of the first growth flush was complete characteristics of the bearers were recorded, on the plant. These were length, diameter of the tip, number of shoots produced, and the length of the first growth flush. At the end of February, 1994, one bearer from each plant was picked with a thinning cut and taken to the laboratory for analysis. Characteristics of the shoots produced were recorded.

Single plants were used per treatment, replicated thirty times. The trial was laid out as a randomised complete block design with 10 replications each of three pruning dates which resulted in annual flowering and three pruning dates which resulted in biennial flowering. Data was analysed using the GLM procedure of SAS (SAS Institute Inc., 1990).

RESULTS

Experiment 1

Table 1 shows the initial conditions of bearers immediately after pruning in April, 1993. Bearer length and total number of buds on the bearer obviously decreased with increasing pruning severity. The number of buds per centimeter bearer length was not the same for all pruning severities. The shortest bearers and the longest bearers, produced by the most severe and the least severe heading cuts respectively, showed the highest concentration of buds, indicating that internode length at the base of a flush was shortest.

The number of shoots produced per bearer was affected by both diameter of bearer and position of heading cut (Table 2). Only the second most severe heading cut, where half of the first flush was left, showed no influence of diameter on the number of shoots produced. All other pruning severities produced more shoots per bearer on thick bearers compared with thin bearers. Both flowering and non-flowering shoots were included.

Heading at the intercalation between the first and second growth flushes produced longer shoots than any other length of bearer used (Table 2). The diameter of the bearer also played a role. Thick bearers produced shoots of longer mean length than thin bearers, for all pruning severities.

Shoots longer than 40cm represent the potential export crop of 1995. There was interaction between pruning severity and bearer diameter with respect to the number of shoots longer than 40cm (Table 2). In all except the least severe pruning, where there was no difference between thick and thin bearers, more long shoots were produced by thick rather than thin bearers.

Thick bearers produced more flowers than thin bearers, although within the pruning severities there was a significant floral gradient (Table 2). The least severe pruning produced the most flowers and the most severe pruning the least flowers. Although these differences appear small, they were means of 5 bearers on plants which have between 30 and 60 bearers in total, and would result in pronounced differences in yield per plant.

Experiment 2

Bearers remaining on plants with a biennial flowering cycle had a significantly larger diameter than bearers on plants flowering annually (Table 3). This difference in bearer diameter resulted in a greater number of shoots arising from bearers on biennial-flowering plants. Although the thicker bearers had more shoots than thinner bearers there was no difference in the mean length of the shoots, or in the diameter of the shoots at the intercalation between the first and second growth flushes (data not shown). The increase in shoot number was due to an increase in number of vegetative shoots, since there was no difference in the number of flowers produced per bearer.

Although there was no difference in the mean shoot length, biennial-flowering plants had more vegetative shoots which were longer than 40cm (Table 4). These shoots represent the potential crop in 1995. The difference is probably due to different numbers of growth flushes. There were no significant differences between annual- and biennial-flowering plants in the number of shoots which consisted of one growth flush only, or had three growth flushes. Plants flowering biennially had more shoots consisting of two flushes and four flushes than annual flowering plants. Shoots with four growth flushes would have started growing the earliest, and consisted of an autumn flush, a spring flush, and two summer flushes.

CONCLUSIONS.

In all aspects, thick bearers gave a better growth response than thin bearers. This was probably not due to differences in carbohydrate reserves in the bearers, since Greenfield, Jacobs & Theron (1994) found very low carbohydrate levels in woody shoots of *Protea* cv. Carnival, and is more likely to be due to better vascular connections in thick bearers for supply of nutrients and plant growth regulators. In roses, Byrne & Doss (1981) showed that daughter shoots are thinner than the mother shoot (bearer).

Of the four different pruning severities tested pruning at the intercalation between the first and second flushes resulted in production of more shoots of better quality, on both thick and thin bearers. Field observation showed that buds arising just below the intercalation were larger and therefore of better quality. These buds were formed near the top of a developing flush, and during development were under less correlative inhibition by plants parts arising distally on the shoot. This weaker correlative inhibition leading to improved development was demonstrated in tulips, where the most distal bulb scale produced the largest daughter bulb (De Hertogh *et al.*, 1983).

The practise of leaving short bearers to maximise flower stem length is not advisable, unless the bearers remaining are thick. Thin, short bearers give rise to few, short shoots.

Heading a protea shoot into old, bare wood will not induce lateral shoot formation. Stems which have no leaves have no viable buds, and adventitious buds are not generally formed (Brits *et al.*, 1986). Heading into two-year-old wood of shoots of *Protea* cv. Carnival still gave a good growth response. The bearers remaining after picking and pruning of biennial-flowering plants were two-years-old. The leaves persist on stems of *Protea* cv. Carnival into the second year, so axillary buds remain viable. The suspected improved vascular connections of the thicker, two-year-old bearers resulted in a growth response superior to that of one-year-old bearers on annual bushes

Although this research does not, and was not aimed at, identifying the critical minimum length and diameter of bearers leading to acceptable shoot growth, it does give an indication of the optimum length of bearers to maximise yield, and does highlight the need for thick rather than thin bearers.

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Table 1:- Initial bearer characteristics following different pruning severities of *Protea* cv. Carnival shoots.

	Pruning severity (growth flushes remaining)			
	1+½	1	½	¼
Bearer length (cm)	32.3	22.2	13.6	7.7
Number buds	29.5	19.3	11.3	7.9
Buds/cm	0.94 b	0.89 bc	0.85 c	1.03 a

Table 2:- Effect of pruning severity and bearer diameter on shoot characteristics of *Protea* cv. Carnival.

Shoot characteristic	Bearer diameter[1]	Pruning severity[2](A) (growth flushes remaining)				Bearer diam[3](B)		Prob>F[4]		
		1+½	1	½	¼	Thin TN	Thick TK	A	B	AxB
Number per bearer	TN	2.06[c]	2.26[bc]	2.23[bc]	2.03[c]			0.0026	0.0001	0.0002
	TK	2.43[b]	3.49[a]	2.66[b]	2.49[b]					
Mean length (cm)	TN+TK	33.0[b]	38.8[a]	35.5[b]	33.9[b]	31.3[b]	39.3[a]	0.3104	0.0001	0.0893
Number >40cm	TN	0.34[c]	0.51[c]	0.43[c]	0.47[c]			0.0138	0.0001	0.0341
	TK	0.54[c]	1.69[a]	1.26[ab]	1.01[b]					
Number of flowers	TN+TK	0.43[a]	0.33[ab]	0.13[bc]	0.08[c]	0.12[b]	0.36[a]	0.1035	0.0104	0.8712

[1]Data pooled across pruning severities and bearer diameters for non-significant interactions, with TN and TK indicating Thin and Thick, respectively.
[2]Values in the same row followed by different superscripts indicate significant differences ($P<0.05$) according to the LSD test.
[3]Values in the same row followed by different superscripts indicate significant differences ($P<0.05$) according to the LSD test.
[4]Two-way ANOVA table with randomised complete block design for Factor A (pruning severity), with Factor B (bearer diameter) a split plot on A.

Table 3:- Characteristics of bearers, and shoots arising from bearers, on *Protea* cv. Carnival plants flowering annually or biennially.

Flowering cycle	Bearer diameter (mm)	Number of shoots/bearer	Mean shoot length (cm)	Number of flower/bearer
Annual	9.81	2.38	52.81	0.72
Biennial	11.07	3.38	52.68	0.66

ANOVA

Source			Significance	
Annual vs Biennial	0.0007	0.0023	0.9749	0.7689

Table 4:- Characteristics of shoots arising from bearers on *Protea* cv. Carnival plants flowering annually or biennially.

Flowering cycle	Vegetative shoots		Vegetative shoots with			
			one	two	three	four
	Total	> 40cm	growth flushes			
Annual	1.69	1.10	0.38	0.17	0.59	0.55
Biennial	2.72	1.79	0.38	0.55	0.66	1.14

ANOVA

Source			Significance			
Annual vs Biennial	0.0062	0.0189	1.000	0.0461	0.6905	0.0383

5. STATISTICS.

Data is stored on diskette located in pocket attached to rear cover. Data input files are either stored as Quattro Pro worksheets and have a WQ1 extension or as SAS files transferred to MS WORD vers. 5 and have a DOC extension. Analysis of variance tables were transferred from SAS to MS WORD vers. 5 and have a DOC extension.