ELSEVIER

Scientia Horticulturae 83 (2000) 311–324

SCIENTIA HORTICULTURÆ

www.elsevier.com/locate/scihorti

Productivity of three rose cultivars (*Rosa hybrida*) trained in a 'vase-shaped' form and grown in a commercial glasshouse in a Mediterranean environment

J.M. Mosher*, D.W. Turner

Plant Sciences, Faculty of Agriculture, The University of Western Australia, Nedlands, WA 6907, Australia

Accepted 22 July 1999

Abstract

A survey was conducted over 12 months to determine productivity and compare the relationships between the different shoot types of three rose cultivars of different ages. The plants were trained in a 'vase-shaped' architecture. Data were collected on 1 year-old 'Sonia', 8 year-old 'Gabrielle' and 7 year-old 'Kardinal'. The ratio of basal shoots : branches : shoots (flowering and non-flowering shoots) over one season was 1 : 2 : 7 (Sonia), 1 : 3 : 8 (Gabrielle) and 1 : 3 : 11 (Kardinal). Of the shoots produced, 44% (Sonia), 29% (Gabrielle) and 19% (Kardinal) were marketable stems and the remainder were either unmarketable (discarded after harvest) or blind shoots (not harvested). A high number of unmarketable stems occurred in summer and were associated with high temperatures and the marketing requirement to harvest the entire crop over 2–3 days. The majority of blind shoots were <5 cm long and formed on the upper half of shoots or branches and in the upper half of the leaf-canopy. Although harvested stem production was positively correlated with the number of branches, increasing branch numbers does not necessarily increase the number of harvested stems in direct proportion. This has implications for plant management and harvesting techniques. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: *Rosa hybrida*; Shoot architecture; Basal shoots; Branches; Blind shoots

* Corresponding author. Current address: P.O. Box 7030, Cloisters Square, Perth, WA 6850, Australia.

0304-4238/00/$ – see front matter
PII: S0304-4238(99)00089-8

1. Introduction

Glasshouse roses have three shoot types that are usually trained into a vase-shaped arrangement. Basal shoots, that form the framework of the plant, sprout from axillary buds on the primary shoot (Kool and Van de Pol, 1993). Flowering shoots, the economically valuable portion of rose plants, sprout from axillary buds on structural laterals and non-flowering or blind shoots form in a similar manner but the flower buds abort during early development (Zieslin and Halevy, 1975). When plants are established, flowering and non-flowering shoots sprout from structural laterals (Kool and Van de Pol, 1993) or branches (Zieslin et al., 1973).

Research into the relationships between shoot types in terms of stem production is minimal and to some extent, contradictory. It has generally been accepted that increasing the number of basal shoots per plant results in increased stem production (De Vries and Dubois, 1983). However, Kool (1996) found that stem production per m^2 was almost unchanged after four years, despite an 83% increase in basal shoots per m^2. Furthermore, the diameter and number of second order laterals per m^2 accounted for 70% of the variation in the number of flowering shoots compared with basal shoots, which accounted for only 30% of the variation (Kool, 1997). This implies that branching determines the number of flowering stems and it has been recommended that an optimum number of structural laterals at a given height above ground level be maintained for good flower production (Kool and Van de Pol, 1993). This highlights the importance for rose productivity of harvesting techniques and the number of shoots that are allowed to develop on branches (Kool and Van de Pol, 1993).

In a commercial glasshouse, stem production per m^2, in terms of harvested stems, is known. However, the number of harvested stems in relation to the number of branches and basal shoots and the proportion of harvested stems to unmarketable stems and blind shoots is unknown. The purpose of this survey was to determine the productivity and compare the relationships between the different shoot types of three rose cultivars in a commercial glasshouse in Western Australia. Information from this survey will provide the basis for assessing the performance of roses with alternative shoot arrangements.

2. Materials and methods

2.1. Glasshouse environment and plants

At Forrestdale, Western Australia, (Lat. 32°S) 19 different rose cultivars are grown in an east–west orientation in two glasshouse covering an area of approximately 1.38 ha. Three cultivars, Sonia, Gabrielle and Kardinal of *Rosa*

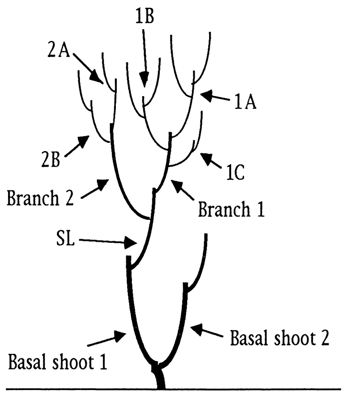

Fig. 1. Diagram of a rose plant indicating how shoots were classified. Structural laterals (SL) between basal shoots and branches were not included in the classification because they die not produce shoots.

hybrida, whose shoots were maintained in a vase-shaped form, were selected for this study. Cultivar Sonia produces salmon pink flowers on stems that are 55–75 cm long. Cultivar Gabrielle produces bright red flowers on stems that are 30–60 cm long and Kardinal also produces bright red flowers on stems that are 45–65 cm long (Pertwee, 1995). In these glasshouses cultivars Gabrielle and Kardinal produce many blind shoots while Sonia produce few. The age of plants at the beginning of the survey was one (Sonia), eight (Gabrielle) and seven (Kardinal) years-old.

Two 1.0 m wide blocks of each cultivar were randomly selected. For Sonia there were 14 plants per block covering an area of 1.75 m^2 (8.0 plants per m^2). For Gabrielle there were 18 plants per block covering an area of 2.09 m^2 (8.6 plants per m^2) and for Kardinal there were 16 plants per block covering an area of 1.67 m^2 (9.6 plants per m^2). Basal shoots and branches of each plant were tagged (Fig. 1).

2.2. Measurements

Three levels of shoot architecture were investigated in this survey: basal shoots, branches and developing shoots. Subsets of branches were reproductive, blind and ‘pants’ shoots. From June 1995 to June 1996, data were collected at three-week intervals on all tagged plants. A three-week time interval ensured that all harvested stems were included, as the minimum interval from one harvest to the next on the one shoot, can be 28 days. For each shoot present (eg. shoot 1A, Fig. 1), the following information was recorded:

- The number of developing shoots (at least 1 cm long) per branch.

- The number of flower buds present per branch and their size (small, medium or large).
- The number of harvested stems, based on the 'flower buds present' category. This is greater than the number of stems actually marketed because a number of harvested stems are culled during post-harvest processing.
- The number of unmarketable stems, which included distorted or bent flowering stems, stems with malformed flower buds or short (<20 cm) flowering stems.
- The number, length and relative position of blind shoots within the leaf-canopy. Blind shoots were classified as either short (<5 cm), medium (5–20 cm) or long (>20 cm), whether they arose from the upper half or lower half of a shoot and whether they were in the upper (not shaded) or lower (shaded) sections of the leaf-canopy.
- The death, or removal by pruning, of the plant, basal shoot or branch were also recorded.

Basal shoots emerged within 10 cm of the scion–rootstock graft. Branches were shoot sections that supported one to four branches or flowering shoots. Developing shoots were either flowering or non-flowering. Other flowering shoots that formed below the leaf-canopy and above the rootstock–scion graft were called pants shoots, which is the colloquial term given to these shoots that do not meet market requirements.

The remaining sections of previous flowering shoots, of which there were up to seven in sequence in the older cultivars Kardinal and Gabrielle, were treated as a single shoot because they provided a continuous vascular connection between the basal shoots and the branches. Because the cultivar Sonia was only 1 year-old, it had fewer of these connecting sections.

Cultural practices and harvesting techniques were uniformly applied to all plants in the glasshouses according to commercial practice. During winter, all plants were lightly pruned and for most of the 12 months non-productive or weak growth was 'turned in' (bent over towards the centre of the row) instead of being removed from the plant by pruning. Cultivars Gabrielle and Kardinal were 'topped' (all flowering shoots removed regardless of their development stage) in late December and early January (mid-summer in the Southern hemisphere) and the flowering stems were 'flush' harvested (harvesting of entire crop over two or three days) for the St. Valentine's Day market (14th February).

2.3. Data analysis

Analysis of variance was used to compare the mean number of basal shoots, branches and blind shoots per plant and the total number of harvested and unmarketable stems between cultivar blocks and between seasons. Data are presented as means or totals for each season (three months).

3. Results

The three cultivars did not differ ($p > 0.05$) in the number of basal shoots, branches or blind shoots per plant or the total number of harvested and unmarketable stems. Despite the differences in plant age, at least one plant died in each block of plants. Plant death occurred primarily in winter.

3.1. Basal shoots

The number of basal shoots per m^2 across four seasons were not different ($p > 0.05$) among cultivars (Table 1). The number of new basal shoots that formed in Gabrielle was almost the same as the total number of basal shoots that died. The number of new basal shoots that formed in cultivars Kardinal and Sonia was approximately half the total number that died.

In Gabrielle and Kardinal new basal shoots formed during spring and summer compared with Sonia where they also formed in winter (albeit late winter, data not shown). In cultivars Kardinal and Sonia approximately 74% of basal shoots died during autumn and winter, compared with Gabrielle where 53% died during the same seasons. Of the new basal shoots per m^2 that formed, 6% in Gabrielle and 11% in Kardinal died during the same year (Table 1).

Table 1
The number of basal shoots, new basal shoots and basal shoots that died in rose cultivars Sonia (1 year-old), Gabrielle (8 year-old) and Kardinal (7 year-old) over four seasons from June 1995 to June 1996[a]

Cultivar	Season				Year	
	Winter	Spring	Summer	Autumn	Total	Mean
Sonia						
Basal sh.	21.4 (1.7)	21.9 (1.8)	22.5 (2.0)	20.0 (1.9)		21.5 n.s.
New basal sh.	0.57	1.14	0.86	0.00	2.57	
Basal sh. that died	1.43	0.86	0.57	2.57	5.43	
Gabrielle						
Basal sh.	22.9 (1.6)	23.5 (1.6)	26.8 (1.9)	25.2 (1.9)		24.6 n.s.
New basal sh.	0.0	2.36	1.42	0.00	3.78	
Basal sh. that died	0.94	0.47	1.42	0.94	3.77	
Kardinal						
Basal sh.	18.9 (1.8)	17.7 (1.6)	20.4 (1.7)	20.2 (1.9)		19.3 n.s.
New basal sh.	0.00	0.96	1.92	0.00	2.88	
Basal sh. that died	2.24	0.31	0.93	1.55	5.03	

[a]Basal shoots emerged within 10 cm of the scion–rootstock graft. Data are expressed per m^2. Values in parentheses are standard error. Statistical significance across seasons: n.s. = not significant ($P > 0.05$).

3.2. Branches

Cultivar Gabrielle (8 year-old) had 39% and Kardinal (7 year-old) had 22% more branches per m^2 than 1 year-old Sonia and the number of branches per m^2 across the four seasons was not different ($p > 0.05$) for each cultivar (Table 2). The number of branches of Gabrielle that died were half the number that died on Sonia plants, while there was no difference between the number of branches that died on cultivars Kardinal and Sonia. Across all cultivars, 60% of branches died during autumn and winter (Table 2). Similar to basal shoots, pants shoots formed during spring and summer and for Kardinal, 12% formed in autumn (Table 2).

3.3. Harvested, unmarketable stems and blind shoots

1 year-old Sonia plants were more productive than 8 year-old Gabrielle (20%) and much more productive than 7 year-old Kardinal (72%) (Table 3). The total number of harvested stems per m^2 across four seasons was not different ($p > 0.05$) for cultivars Gabrielle and Sonia. For Sonia the number of harvested stems were

Table 2
The number of branches, branches that died and pants shoots present on rose cultivars Sonia (1 year-old), Gabrielle (8 year-old) and Kardinal (7 year-old) over four seasons from June 1995 to June 1996[a]

Cultivar	Season				Year	
	Winter	Spring	Summer	Autumn	Total	Mean
Sonia						
Branches	51.4 (4.9)	47.4 (4.4)	46.5 (4.5)	38.8 (4.5)		46.0 n.s.
Branches that died	7.4 (15%)	4.0 (8%)	4.3 (9%)	8.6 (22%)	24.3	6.1 (14%)
Pants	0.0	2.6	1.1	0.0	3.7	
Gabrielle						
Branches	66.7 (5.0)	65.4 (4.3)	64.6 (4.0)	58.6 (4.4)		63.8 n.s.
Branches that died	5.4 (8%)	4.3 (7%)	5.0 (8%)	2.6 (4%)	17.2	4.3 (7%)
Pants	0.0	1.2	0.5	0.0	1.7	
Kardinal						
Branches	61.5 (5.4)	53.6 (5.2)	54.5 (4.8)	51.5 (4.6)		55.3 n.s.
Branches that died	9.6 (16%)	3.1 (6%)	5.0 (10%)	5.6 (11%)	23.2	5.8 (10%)
Pants	0.0	3.1	1.6	0.6	5.3	

[a]Branches supported the leaf-canopy and reproductive shoots. Pants shoots formed below the leaf-canopy and above the rootstock–scion graft. Data are expressed per m^2. Values in parentheses are standard errors or %, as indicated. Statistical significance across seasons: n.s. = not significant ($P > 0.05$).

Table 3
The number of marketable stems, unmarketable stems and blind shoots in rose cultivars Sonia (1 year-old), Gabrielle (8 year-old) and Kardinal (7 year-old) over four seasons from June 1995 to June 1996[a]

Cultivar	Season				Year	
	Winter	Spring	Summer	Autumn	Mean	LSD
Sonia						
Marketable	69 (51%)	73 (45%)	69 (42%)	69 (40%)	70	n.s.
Non-marketable	15 (12%)	22 (13%)	39 (24%)	35 (20%)	28	12
Blind	50 (37%)	68 (42%)	55 (34%)	70 (40%)	61	n.s.
Total	134	163	163	174		
Gabrielle						
Marketable	52 (31%)	58 (31%)	61 (28%)	65 (28%)	59	n.s.
Non-marketable	6 (3%)	14 (8%)	71 (31%)	38 (17%)	32	13
Blind	110 (66%)	114 (61%)	89 (41%)	127 (55%)	110	n.s.
Total	167	186	221	230		
Kardinal						
Marketable	29 (15%)	45 (22%)	49 (22%)	40 (17%)	41	14
Non-marketable	8 (4%)	7 (4%)	23 (10%)	12 (5%)	13	6
Blind	153 (81%)	151 (74%)	152 (68%)	181 (78%)	159	n.s.
Total	190	203	224	233		

[a] Data are expressed per m^2. Values in parentheses are percentages of the total number of shoots. Statistical significance across seasons: n.s. = not significant, LSD at $P > 0.05$.

remarkably uniform ($p = 0.97$) across all seasons. The total number of harvested stems for Kardinal during winter was at least 27% less than harvested stems during the other seasons.

Of the flowering stems per m^2 that were produced over 12 months, 35% (Gabrielle), 23% (Kardinal) and 28% (Sonia) were unmarketable. The majority of unmarketable stems occurred during summer and the least in winter or spring.

1 year-old Sonia produced the least number of blind shoots per m^2 per year, 44% less than 8 year-old Gabrielle and 62% less than 7 year-old Kardinal (Table 3). The number of blind shoots per m^2 was not different ($p > 0.05$) across seasons. Between cultivars, there was no consistent pattern in blind shoot formation except that most formed during autumn (Table 3).

Most shoots per m^2 were present during autumn, while the least were present during winter. The percentage of blind shoots was higher than that of harvested stems per m^2 across seasons in the older cultivars Gabrielle and Kardinal but the reverse occurred in the younger Sonia, except for autumn where the percentage of blind shoots and harvested stems were the same (Table 3).

Table 4
Ratios of the number of (a) branches (b) harvested stems (c) total shoots (ie. flowering and non-flowering shoots) to the number of basal shoots of rose cultivars Sonia (1 year-old) Gabrielle (8 year-old) and Kardinal (7 year-old) over four seasons from June 1995 to June 1996

Cultigvar	Season											
	Winter			Spring			Summer			Autumn		
	a	b	c	a	b	c	a	b	c	a	b	c
Sonia	2.4	3.2	6.3	2.2	3.3	7.4	2.1	3.1	7.2	1.9	3.5	8.7
Gabrielle	2.9	2.3	7.4	2.8	2.5	8.0	2.4	2.3	8.3	2.3	2.6	9.3
Kardinal	3.3	1.5	10.1	3.0	2.5	11.5	2.7	2.4	11.0	2.5	2.0	11.5

3.4. Shoot ratios

The highest number of branches per basal shoot occurred in winter and the lowest in autumn for all three cultivars (Table 4). In contrast, the highest number of shoots (i.e. flowering and non-flowering) occurred in autumn and the least in winter. This is consistent with all plants being lightly pruned during winter (data not shown). 7 year-old Kardinal had the most branching and 1 year-old Sonia the least (Table 4).

The mean ratio of the number of marketable stems to the number of branches over four seasons was 1.54 ± 0.11 for the younger Sonia and, for the older cultivars, 0.94 ± 0.07 for Gabrelle and 0.74 ± 0.10 for Kardinal.

3.5. Harvested stems

An increase in the number of basal shoots and branches per plant was associated with an increase in stem production in all cultivars (Fig. 2). Stem production per basal shoot and per branch increased at least 2.5–2.9 times more in cultivars Gabrielle and Sonia than in Kardinal (Fig. 2).

Irrespective of the number of basal shoots or branches per plant, some plants of all cultivars produced few marketable shoots over a year. In the young Sonia and the older Kardinal, large numbers of shoots were harvested (per basal shoot or branch) only when there were few basal shoots per plant (data not shown). This pattern was not obvious for Gabrielle.

3.6. Blind shoots

There were 2–4 times more short than medium blind shoots and at least four times more short than long blind shoots (Table 5). 10–15 times more blind shoots formed on the upper rather than the lower half of branches and 1.5–2.6 times

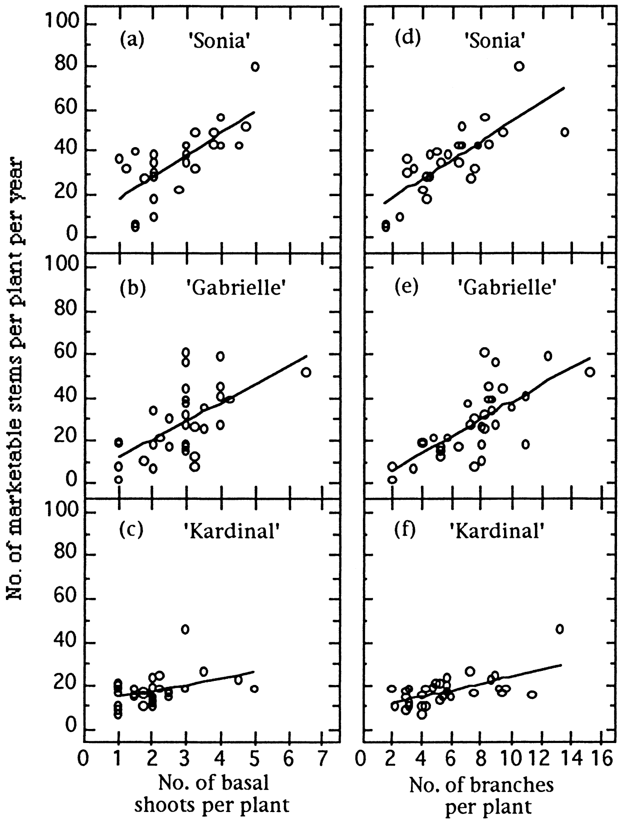

Fig. 2. Relationship between (a,b,c) the number of harvested stems and mean number of basal shoots per plant and (d,e,f) the number of harvested stems and the mean number of branches per plant of rose cultivars 1 year-old Sonia, 7 year-old Gabrielle and 8 year-old Kardinal from June, 1995 to June, 1996.

more blind shoots formed in the upper rather than in the lower canopy. Of the seven blind shoot categories, there was no change in three of these across seasons for Kardinal (Table 5).

There was no consistent pattern in the length of blind shoots between cultivars and across seasons (Table 5), except that the number of long blind shoots per m^2 during winter and spring was higher than the number of blind shoots per m^2 during summer.

4. Discussion

Of the shoot types dealt with in this survey, the number of branches appears to be the most important in relation to marketable stem production of vase-shaped

Table 5
The number of blind shoots per m^2 according to their length and position in the canopy of rose cultivars Sonia, Kardinal and Gabrielle over four seasons from June 1995 to June 1996[a]

Cultivar	Shoot length and position		Season				Mean	LSD $P = 0.05$
			Winter	Spring	Summer	Autumn		
Sonia	Length	Short	20	40	36	45	35	13
		Medium	19	18	13	19	17	n.s.
		Long	11	9	5	6	8	3
	Shoot	Upper	41	61	51	69	55	18
		Lower	9	6	3	1	5	4
	Canopy	Upper	24	35	39	47	36	13
		Lower	26	33	15	23	24	11
Gabrielle	Length	Short	63	74	60	75	67	n.s.
		Medium	38	28	22	41	32	10
		Long	9	12	6	11	10	4
	Shoot	Upper	97	104	86	123	102	27
		Lower	13	10	3	4	7	6
	Canopy	Upper	67	68	72	103	77	22
		Lower	43	46	17	24	32	15
Kardinal	Length	Short	117	112	122	147	123	n.s.
		Medium	30	30	26	31	29	n.s.
		Long	7	9	3	4	6	4
	Shoot	Upper	129	134	143	174	144	n.s.
		Lower	24	17	9	7	14	8
	Canopy	Upper	98	94	120	150	114	34
		Lower	56	57	32	31	44	20

[a] Blind shoots were short (<5 cm), medium (5–20 cm) or long (>20 cm) and were on the upper or lower half of a branch and in the upper leaf-canopy (sunlit) or lower leaf-canopy (shaded). Statistical significance across seasons evaluated at $P = 0.05$; n.s. = not significant.

rose plants. This is because branches support the productive region of the plant, they account for most variation in stem production and the harvested stem to branch ratio gives an indication of plant efficiency. Also, in this survey the number of branches and blind shoots were positively correlated with plant age and plant height (data not presented). This association is a reflection of the confounding of the effects of age and cultivar, especially in the case of Sonia which was 6 or 7 years younger than the other cultivars.

4.1. Productivity of vase-shaped rose plants

In terms of stem production, the stem to branch ratio is a measure of plant efficiency. Branches of cv Kardinal were least efficient in producing stems compared with branches of Sonia which produced more than one stem per branch. As cultural practices and harvesting techniques were uniformly applied, the difference in plant efficiency could be attributed to age and/or cultivar differences. In relation to plant age, harvesting stems from the first or second 5-leaflet leaf over time increases branching. Remaining stem sections have at least two axillary buds (Zamski et al., 1985) and one or both can from a flowering shoot. An increase in branching may also signify a decrease in the stem to branch ratio as a plant ages.

Kool and Van de Pol (1993) promote the view that too many branches produce a large number of low quality stems along with an increase in the number of blind shoots and suggest that assimilates should be partitioned over an optimum number of branches. The number of branches per m^2 of 1 year-old Sonia (46 per m^2) were in the optimum range quoted by Kool and Van de Pol (1993) for a temperate environment. This implies that the older cultivars, Gabrielle and Kardinal, had too many branches. Although stem quality was not measured in this survey, the number of blind shoots were, and these data, for each cultivar, would support the argument that plants with many branches produce a high number of blind shoots (Kool and Van de Pol, 1993). According to Kool and Van de Pol (1996), rose plants reach maximum stem production in their second year (Sonia in this survey was in its second productive year). This coincides with full leaf-canopy closure (Kool, 1996) where about 90% of incoming light is intercepted (Kool and Lenssen, 1997). This level of light interception continues in Western Australia over subsequent years (Ukich, 1993), yet stem production in temperate climates declines after the second year (Kool and Van de Pol, 1996).

With older plants, such as cultivars Gabrielle and Kardinal, management options that will increase productivity will most likely decrease stem production temporarily. However, with young plants such as Sonia, the number of branches per m^2 could be managed by selectively removing or bending over weak growth and slowing the increase of plant height by harvesting stems on lower internodes. The data presented here provide the basis for comparing the performance of alternative shoot arrangements that have the objective of increasing productivity (Mosher, 1998).

4.2. Effect of seasons on shoot types

The number of shoots, whether basal, branches, harvested stems or blind shoots, were similar across all seasons for all cultivars, except the number of harvested stems of 7 year-old Kardinal. In contrast, the number of unmarketable stems of the older cultivars Gabrielle and Kardinal was higher in summer than in other seasons, whereas the number of unmarketable stems of the younger Sonia was high in summer and autumn.

The high number of unmarketable stems during summer could be attributed to high temperatures that increase the number of flowering shoots per plant (Moe, 1988) but reduce stem length and hence, stem quality (Moe and Kristoffersen, 1969). These stems would be rejected in post-harvest grading, leading to increased labour requirements. This occurred in all cultivars, yet it was accentuated in the red cultivars (ie. Gabrielle and Kardinal) that were managed to produce a flush harvest for 14th February. The number of unmarketable stems is likely to increase when plants are flush harvested because of increased competition between shoots that are developing simultaneously (Kool et al., 1997).

4.3. Blind shoots

The pattern of blind shoot formation in this survey was similar for all cultivars. Most blind shoots were less than 5 cm long, and formed on the upper half of shoots or branches and in the upper half or sunlit section of the least canopy. This distribution is similar to that found by Ukich (1993) but differs from other reports where low light intensity and low temperatures promoted blind shoot formation (Moe, 1971).

Most literature that deals with blind shoot formation in roses considers only long shoots which are about a third to half the length of a flowering shoot (Moe, 1971; Zieslin and Halevy, 1975; Nell and Rasmussen, 1979). Long blind shoots in this survey were the smallest proportion, yet they represent a potential loss of production because they were more likely to produce a flower than medium or short blind shoots. The higher number of long blind shoots during winter and spring compared with the lower number formed during summer is consistent with the effects of low temperatures and possibly low light on blind shoot formation (Moe, 1971).

Of greater importance is the high number of short and medium length blind shoots (especially on the older cultivars Gabrielle and Kardinal) that do not flower. Associated with these blind shoots are a high number of branches per m^2 which are probably of small diameter and exposed to full sunlight. Also, these branches have no flower or vigorous vegetative growth which, if present, has an inhibitory effect on lower axillary buds (Zieslin et al., 1973). Therefore, axillary buds are able to sprout probably in response to high light (Mor and Halevey, 1984) and low concentrations of inhibiting substances but they fail to develop into flowering shoots (Kool and Van de Pol, 1993).

A high number of branches and blind shoots per m^2 indicates that there are too many growing points and that selective removal of bending in of weak, or small diameter branches, will probably reduce demand on the assimilate pool while not reducing stem production (Kool and Van de Pol, 1993).

4.4. Death and renewal of basal shoots and branches

Plant productivity and longevity depends upon basal shoot formation during the establishment phase of a rose plant and occasional basal shoot renewal during subsequent years (Marcelis-van Acker, 1993). Measuring basal shoot death and renewal over one year, of a possible 10-year productive life, may not be a reliable indicator of future productivity. It was somewhat surprising therefore, to find that basal shoot death and renewal in 8 year-old Gabrielle plants was the same. However, basal shoot death in 1 year-old Sonia and 7 year-old Kardinal plants was twice as high as basal shoot renewal. Over the year of this survey, Gabrielle plants were sustaining themselves, while Sonia and Kardinal were losing potential productive sites.

The high rate of basal shoot death in Kardinal may be an indication that the plants are approaching the end of their productive life. Yet, for the 1 year-old Sonia, the high rate of basal shoot death of 14% per year would need to be matched by an equivalent rate of basal shoot production to maintain productivity in the longer term.

A similar relationship existed between cultivars in relation to branch death. Mean branch death over a season was 7% for Gabrielle and 14% for Sonia. The rate of basal shoot and branch death of Sonia would appear inconsistent with the comments made previously regarding the optimum number of branches per m^2 and may be due to natural thinning after the plant establishment phase and may therefore, be transient.

In forest species, death or abscission of branches can be caused by shading, high plant density, warm and humid conditions, water availability (Kozlowski, 1973) or competition between plant parts that reflect differences in nutritional, hormonal and metabolic levels (Addicott and Lyon, 1973). Here it was observed that basal shoot and branch death were associated with leaf shading and a relatively low growth rate (data not presented). This may by the reason why the rate of shoot death was high during autumn and winter, although this was not consistent as a high proportion of basal shoots and branches of Gabrielle died during summer. Furthermore, the distribution of basal shoot and branch death was similar across plants that had one to six basal shoots (data not presented), indicating that regardless of plant size or vigour, all plants had some shoots that died. This is also consistent with uniform plant death across cultivars. It would appear therefore, that basal shoot and branch death is a natural thinning process that occurs in response to environmental conditions created by plant density.

Acknowledgements

We would like to thank the Horticultural Research and Development Corporation and Floraco Ltd. for financial support. We thank Floraco Ltd. for advice, support and access to their plants.

References

Addicott, F.T., Lyon, J.L., 1973. Physiological ecology of abscission. In: Kozlowski, T.T. (Ed.), Shedding of Plant Parts. Academic Press, New York, pp. 85–124.

De Vries, D.P., Dubois, L.A.M., 1983. Relations between basal bottom-breaks and harvested shoots in own-rooted hybrid tea-rose seedlings and their clones. Gartenbauwissenschaft 48, 189–192.

Kool, M.T.N., 1996. Long-term flower production of a rose crop. II. The importance of new basal-shoot formation. J. Hortic. Sci. 71, 445–452.

Kool, M.T.N., 1997. Importance of plant architecture and plant density for rose crop performance. J. Hortic. Sci. 72, 195–203.

Kool, M.T.N., De Graaf, R., Rou-Haest, C.H.M., 1997. Rose flower production as related to plant architecture and carbohydrate content: Effect of harvesting method and plant type. J. Hortic. Sci. 72, 623–633.

Kool, M.T.N., Lenssen, E.F.A., 1997. Basal-shoot formation in young rose plants: Effects of bending practices and plant density. J. Hortic. Sci. 72, 635–644.

Kool, M.T.N., Van de Pol, P.A., 1993. Controlling the plant development of *Rosa hybrida* 'Motrea'. Scientia Hortic. 53, 239–248.

Kool, M.T.N., Van de Pol, P.A., 1996. Long-term flower production of a rose crop. I. The influence of planting system and rootstock clone. J. Hortic. Sci. 71, 435–443.

Kozlowski, T.T., 1973. Extent and significance of shedding of plant parts. In: Kozlowski, T.T. (Ed.), Shedding of Plant Parts. Academic Press, New York, pp. 1–44.

Marcelis-van Acker, C.A.M., 1993. Morphological study of the formation and development of basal shoots in roses. Scientia Hortic. 54, 143–152.

Moe, R., 1971. Factors affecting flowering abortion and malformation in roses. Physiol. Plant. 24, 291–300.

Moe, R., 1988. Growth and flowering in roses. Acta Hortic. 218, 121–130.

Moe, R., Kristoffersen, T., 1969. The effect of temperature and light on growth and flowering of *Rosa* 'Baccara' in greenhouses. Acta Hortic. 14, 157–166.

Mor, Y., Halevey, A.H., 1984. Dual effect of light onflowering and sprouting of rose shoots. Physiol. Plant. 61, 119–124.

Mosher, J.M., 1998. Improving the quality and production of roses for cut flowers. MSc (Hort) Thesis, The University of Western Australia, 165 pp.

Nell, T.A., Rasmussen, H.P., 1979. Blindness in roses: Effects of high intensity light and blind shoot prediction techniques. J. Am. Soc. Hortic. Sci. 104, 21–25.

Pertwee, J., 1995. The Production and Marketing of Roses, 2nd ed. Pathfast Publishing, Essex, UK, p. 127.

Ukich, P.M., 1993. Light as an issue in the productivity of glasshouse roses. Agriculture 400 Research Project, The University of Western Australia, p. 80.

Zamski, E., Oshri, S., Zieslin, N., 1985. Comparative morphology and anatomy of axillary budsalong a rose shoot. Bot. Gaz. 146, 208–212.

Zieslin, N., Halevy, A.H., 1975. Flower bud atrophy in 'Baccara' roses. I. Description of the phenomenon and its seasonal frequency. Scientia Hortic. 3, 209–216.

Zieslin, N., Halevy, A.H., Biran, I., 1973. Sources of variability in greenhouses rose flower production. J. Am. Soc. Hortic. Sci. 98, 321–324.