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Influence of the Quality of Rooted Cuttings on the Growth and Final Quality of Cut Chrysanthemum

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Summary

A series of 5 experiments was conducted to establish whether the quality of rooted cuttings has any effect on the appearance of cut chrysanthemums (*Chrysanthemum indicum* hybrids). Three different chrysanthemum cultivars were examined in a greenhouse (in summer and winter), where the N content of the cuttings (low, moderate and high), the cutting size (small and large) and the root number (full and half) were varied. In a homogeneous group of rooted cuttings, both the N content of the cuttings and the root number were of minor importance, provided that the nutrient and water conditions were not restrictive. However, if rooted cuttings with full and half root numbers were planted side by side in a common bed, the number of flowers and stem weights were lower for the cuttings with the half root count (and accordingly higher for the cuttings with the full root count) than in the corresponding homogeneous group. Cutting size had a major influence on the quality of the cut stems especially in mixed planting. Large cuttings planted in the homogeneous bed had more 5.4 flowers and 25.4 g higher stem weight as compared to small cuttings. These differences were even greater in mixed planting resulting in more than 11.6 flowers and higher stem weight of 31.5 g across all cultivars. Differences in the quality characteristics of the rooted cuttings were not reduced with time in the mixed bed. Therefore, it was concluded that competition in a mixed bed serves to heighten and aggravate the quality differences of rooted cuttings.

Key words. cutting size – N-content – root number – mode of planting – uniformity – *Chrysanthemum indicum* hybrids

Introduction

With about two billion cut stems produced every year, the chrysanthemum remains one of Europe's most popular cut flowers. Furthermore, it is important as cut flower produced in the open field. In contrast with the pot chrysanthemum, where unrooted cuttings are increasingly planted into the final pot, the production of cut chrysanthemums still relies on the planting of rooted cuttings. However, supplied rooted cuttings are not always of uniform quality and the rooting intensity is sometimes difficult to assess when cuttings are propagated in compressed peat pellets.

The quality of a rooted chrysanthemum cutting is largely influenced by the initial quality of the cutting. Although the rooting response in terms of rooting percentage, number of roots and decay rate can also be influenced by storage and propagation conditions (Pol 1988; Rajapakse et al. 1992, 1996; Almeida and Pivetta 2003), the rooting performance of a cutting is already predetermined when attached to the stock plant (Haissig et al. 1986). Previous research demonstrated that the N supply to the stock plants (together with the fresh mass of the cuttings) has a substantial effect on the root development of the cuttings (Kadner and Zerche 1997; Zerche et al. 1999, 2002). When the N content in 'Puma' cuttings was increased, fresh masses ranging between 0.89 and 1.61 g were obtained, as were root numbers per cutting of between 8 and 14. However, the after effect of increasing N content in cuttings on subsequent growth and development of rooted cuttings is still unknown.

Results in a number of scientific articles indicate that the number of roots per cutting can be of direct importance for axillary bud growth and plant growth. It has been shown that after 69 days from cutting/planting, fresh weight of leaves and stems in *Origanum, Mentha* and *Melissa* was higher in cuttings with many roots than in cuttings with few roots (Kuris et al. 1980). The number of leaves per plant, fresh weight of leaves, and dry weight of *Pelargonium peltatum* plants was positively correlated with the number of roots (Gad et al. 1987). As cytokinin synthesis mainly occurs in the root tips (Davies 2004), the number of roots could affect growth and development of the shoot independent on uptake of water and nutrients.. In addition to effects of root number, the shoot size, which is sometimes variable among delivered cuttings, may influence subsequent growth and development. When cuttings of different qualities are planted side by side in a same bed, competition for growth factors may add to quality differences among the cut flowers. Focusing on chrysanthemum, the effects of the growth conditions on the visual quality of cut flowers have been largely studied (Carvalho and Heuvelink 2001). However, little research is known about the influence of the quality of rooted cuttings on the final quality of cut chrysanthemum.

One condition for the use of modern methods to produce cut chrysanthemums – and the use of harvesting machines – is homogeneity of the flowerbeds. The required uniformity of the plants can only be achieved if the cuttings are of exactly equal size, independent of the type of rooting. Large producers of cuttings have been classifying their cuttings by weight (one category for every weight increase of 0.2 g) for years. The most common weight categories are 0.8, 1.0, 1.2, 1.4 and 1.6 g (MEGGELEN-LAAGLAND 1996). Other producers configure the automatic seeding process in such a way that cuttings of an even length are produced (EVANS 2005)

The aim of the present study was, to evaluate the influence of nitrogen status, size and root number of chrysanthemum cuttings on subsequent growth and final external quality of cut flowers, particular considering mixed planting of different cutting qualities.

Materials and Methods

Three cultivars were cultivated in a greenhouse under controlled environment for three years both in summer and in winter (5 experiments). The test procedure and treatments of unrooted and rooted cuttings and the climatic conditions are presented in Table 1. A stock plant cultivation method was established to produce cuttings of different quality levels. Root development was examined through the use of perlite as a sticking medium. Cuttings were placed in greenhouse under long day conditions and intermittent mist. The plant density during the root production phase was 400 cuttings per m^2.

The cut flower experiments were conducted – in line with common commercial practice – using thin-layer culture on greenhouse tables in ED 73 standard soil (white peat and clay). Water and liquid fertilizer were supplied continuously through drip tubes. The nutritional content of the substrate never fell below the values indicated in Table 1, ensuring that growth and development were not restricted.

N supply

In Exp. 1 and 2, the influence of N supply to the cuttings on the growth and development of cut flowers was investigated. By supplying the stock plants with different amounts of N (low N-supply 0.8 g N m^{-2} $week^{-1}$, medium N-supply 1.5 g N m^{-2} $week^{-1}$ and high N-supply 4.0 g N m^{-2} $week^{-1}$), different N concentration levels in the unrooted cuttings were generated (Table 2). With the highest N supply, the cuttings developed the classical symptoms of over-supply (grey-blue discolouring of leaves), whereas under a low N supply, cuttings reflected deficiency symptoms (hardening).

Table 1. Details of experiments, treatments and climatic conditions.

Experimental design	• Cultivars: 'Puma weiß', 'Stallion' (2005 'White Fleury'), 'Yellow Relinda' • three replication plots • 25 plants per replication plot • growth on tables in thin layer peat substrate, 64 plants per m^2 • fertilizing by irrigation, high nutrient level: N>300 mg l^{-1}, P>100 mg l^{-1}, K>400 mg l^{-1}
Factors	
Exp. 1 summer	cultivar, root number, nitrogen (C, R, N)
Exp. 2 winter	cultivar, root number, nitrogen (C, R, N)
Exp. 3 summer	cultivar, root number, size + planting (C, R, SP)
Exp. 4 winter	cultivar, root number, size + planting (C, R, SP)
Exp. 5 summer	cultivar, root number + planting (C, R, RP)
Time of growth	
Exp. 1 summer	planting 23.05., short day from 12.06., harvest at 06.08.2001
Exp. 2 winter	planting 05.09., short day from 24.09., harvest at 26.11.2001
Exp. 3 summer	planting 23.05., short day from 12.06., harvest at 06.08.2002
Exp. 4 winter	planting 05.09., short day from 24.09., harvest at 26.11.2002
Exp. 5 summer	planting 23.05., short day from 12.06., harvest at 06.08.2005

Climate data	Day length short day (h)	Day length long day (h)	Temperature short day (°C)	Temperature long day (°C)	PPFD* short day (mol m^{-2} d^{-1})	PPFD* long day (mol m^{-2} d^{-1})
Exp. 1	10.0	14.8	22.2	20.7	8.5	10.4
Exp. 2	9.4	15.3	18.1	21.3	4.2	9.9
Exp. 3	10.0	14.7	22.6	20.3	10.6	11.4
Exp. 4	10.0	15.6	19.2	21.1	4.2	7.5
Exp. 5	10.0	15.5	23.1	21.6	9.5	11.2

*PPFD (daily light integral)

Table 2. Quality of unrooted and rooted cuttings after application of different N supplies to stock plants (Exp. 1) and different cutting sizes (Exp. 3).

Exp. 1	'Puma'			'Stallion'			'Yellow Relinda'		
Unrooted cutting									
N-content	low	normal	high	low	normal	high	low	normal	high
(%)	4.41 c	5.15 b	5.82 a	3.71 c	4.47 b	4.99 a	4.75 c	5.53 b	5.83 a
Rooted cutting									
Root number	9.0 b	10.6 a	15.7 a	20.7 b	22.7 a	25.2 a	8.7 n.s.	8.5 n.s.	9.0 n.s.
Root length (cm)	1.3 b	1.8 a	1.8 a	2.0 b	2.2 a	2.0 a	1.6 n.s	1.6 n.s.	1.8 n.s.
Exp. 3									
Unrooted cutting									
Size	big	small		big	small		big	small	
(cm)	8–9	4–5		8–9	4–5		8–9	4–5	
Weight (g)	2.9 a	0.8 b		2.4 a	0.5 b		2.4 a	0.5 b	
Rooted cutting									
Root number	17.1 a	10.2 b		16.9 a	13.2 b		10.6 a	12.0 a	
Root length (cm)	2.8 a	2.8 a		2.1 a	2.3 a		2.9 a	2.8 a	

Different letters indicate significant differences, within the respective cultivar ($P \leq 0.05$)

Cutting size

In the Exp. 3 and 4, the effect of cutting size, large (8–9 cm) and small (4–5 cm) cuttings, uniform and mixed planted (separate evaluation of large and small cuttings in mixed planted areas) on subsequent development of cut flowers was investigated. Fig. 1 shows the different cutting sizes on example of cultivar 'Puma weiß'.

Special attention was dedicated to the effect of non-homogeneous rooted cutting material by setting up a mixed bed of large and small rooted cuttings. This was undertaken once in a controlled environment culture with a three week long-day phase, and once in a culture without a long-day phase. Table 2 shows that different cutting sizes generated different rooted cutting qualities in terms of root number and length. However, this was dependent on the individual cultivar. The rooting of cuttings of 'Yellow Relinda' was not dependent on the cutting size, whereas the cutting size had a marked influence on rooting of the cultivars 'Puma' and 'Stallion'.

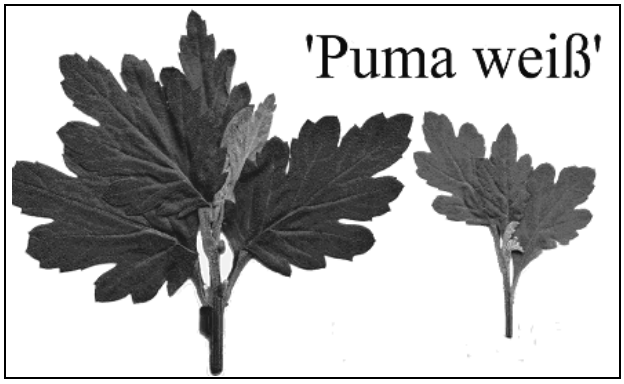


Fig. 1. Comparison of large (8–9 cm) and small (4–5 cm) cuttings on example of cultivar 'Puma weiß'.

Number of roots

In all of the experiments, 50 % of the roots of half the test plants were manually removed before planting to establish the direct effect of root number on the quality of the cut flowers. The effect of root number in a mixed plantation was investigated separate in the Exp. 5. For this purpose, rooted cuttings with full and half root numbers were planted once into separate beds and once into a mixed bed.

Chemical analyses, measurements and statistical evaluation

To establish the N concentration in the dry mass of the cuttings (Exp. 1 and 2), was analysed before sticking. The absolute dry matter content was measured by weighing 5 g of the sample after it had been carefully pre-dried (at 60 °C), ground and fully dried (at 105 °C).

The N concentration (N_t) of the dry mass was measured with the Dumas technique (Ehrenberger 1991). N contents and rooting characteristics of the cuttings are documented in Table 2.

The effect of cutting quality and root number on vegetative growth was assessed by measuring the height of the plants (cm) one week after they had been planted and at the beginning of the short-day phase. At harvest time, the number of open flowers (number stem^{-1}), the stem length (cm stem^{-1}) and the fresh mass of the stems (g stem^{-1}) were determined.

The data were subjected to a variance analysis (ANOVA/MANOVA). Significant differences between mean values were assessed using the Tukey test with P=0.05 (Statsoft 1995) and marked with different letters.

Table 3. Significance of factors (ANOVA).

	Studied parameters	Stem weight	Stem length	Flower number
Exp. 1	Cultivar, root number, nitrogen	C***; R***	C***; R***; C x N**	C***; R**; N***; C x N***
Exp. 2	Cultivar, root number, nitrogen	C***; R***; N**; C x N***	C***; C x N**	C***
Exp. 3	Cultivar, root number, size+planting	C***; R***; SP***	C***; R***; SP***	C***; R**; SP***; C x SP***
Exp. 4	Cultivar, root number, size+planting	C***; R***; SP***; C x SP***; C x SP x R**	C***; R***; SP***; C x S**	C***; R***; SP***; C x SP***; SP x R***; C x SP x R*
Exp. 5	Cultivar, root number+planting	C***; RP***	C***	C***; RP**

C = Cultivar, R = Root number, N = Nitrogen, SP = Size+planting, RP =Root number+planting
***p<0,001, **p<0,01, *p<0,05

Results

The evaluation the five experiments shows that the quality of cut flowers was predominantly influenced by cultivar and also by the time of the year (compare Exp. 1 to 2 and 3 to 4, respectively, Table 2).

Influence of the N supply

The influence of nitrogen on stem weight and length was not consistent for the different experiments and always was subject to interaction with cultivar (Table 3). However, in Exp. 1, the flower number of cultivar. 'Stallion' responded strongly to the nitrogen level (Fig. 4). The flowering was substantially inhibited when nitrogen-deficient cuttings were used, even if the cut culture itself received high amounts of N. N deficiency to cuttings reduced the number of flowers by 14 or 33 % when compared with a high N supply. A similar significant effect was found for the stem length of the same cultivar which, however, was rather small in relative and absolute terms (maximum difference: 4 cm, data not shown).

Influence of the cutting size at end of long day period

In contrast to the N supply, different cutting sizes generated clear and statistically significant height differences at the end of the long-day phase (three weeks after the plants in question had been planted), both in summer (Exp. 3) and in winter (Exp. 4, Fig. 2). The height difference (about 4 cm when the cuttings were planted) increased further during the vegetative growth stage of the long-day phase. At this stage of the experiment, the mode of planting (homogenous versus mixed, in direct competition) had minor influence on plant height. Height differences were substantially more pronounced in winter when there was less light (up to 12 cm) than in summer (about 8 cm). Fig. 3 shows that the growth of small rooted cuttings was substantially slower in winter (Exp. 4).

Even though there was some interaction with other factors (Table 3).

1. **Final stem weight and length:** The cutting size had a major effect on stem weight, both in summer and in winter. At the end of the cultivation period, and dependent on the particular cultivar, the small cuttings, especially in the mixed beds, had only reached about 30 % of the stem weight of the large cuttings. It seemed remarkable that significant differences had developed between small cuttings in separate and mixed beds, as well as between large cuttings in separate and mixed beds, by the time the first flowers emerged (Fig. 5a). This shows that the relative disadvantages of undersized rooted cuttings in heterogeneous beds increased in later growth stages.
2. **Final flower number:** Season and choice of variety continued to have the largest effect on flower number. Because of the close correlation between stem weight and flower number, the results were similar to the results for stem weight. Flower number also demonstrated that the competition of small and large cuttings in the mixed bed prompted the small cuttings of all three varieties to develop even fewer flowers than in the bed with exclusively small cuttings. The small cuttings of the 'Puma weiß' and 'Stallion' cultivars in the mixed bed were affected especially drastically in winter: their flower

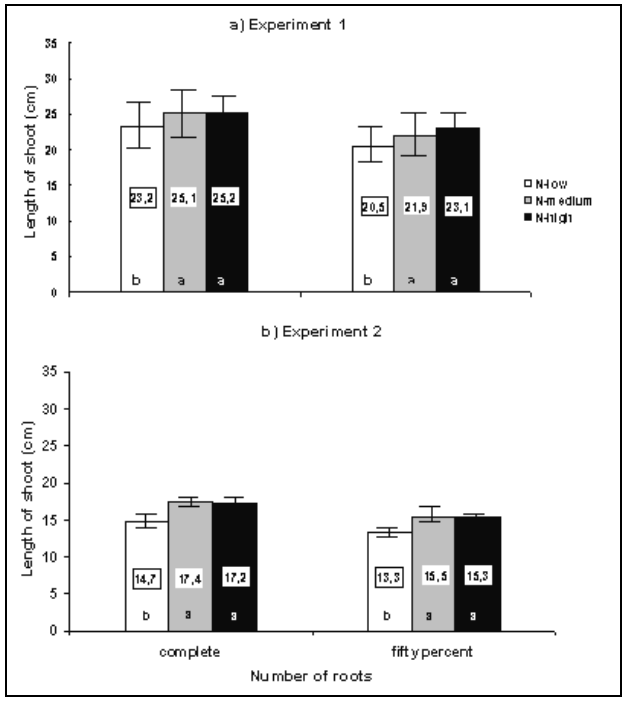


Fig. 2. Effect of number of roots (complete root system and 50 % rootsystem) and nitrogen supply (low, medium and high) on the plant height three weeks after planting at the end of the long day period in a) Exp. 1 and b) in Exp. 2 (means of three cultivars).

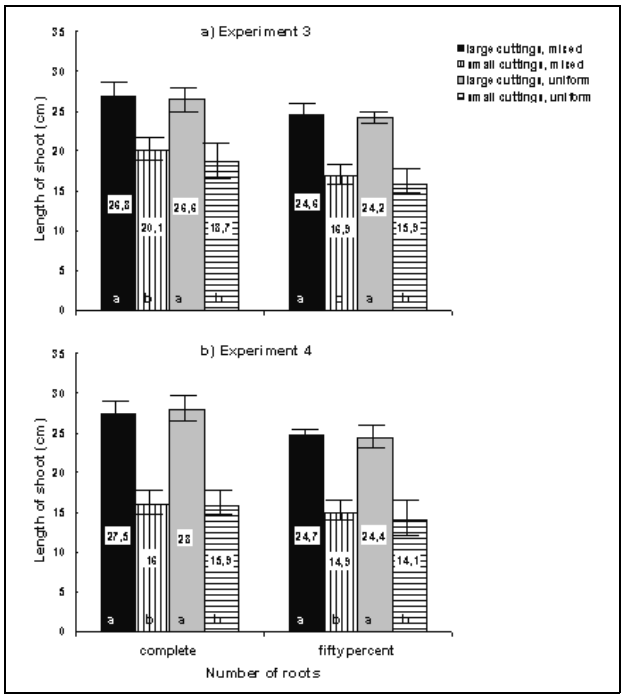


Fig. 3. Effect of number of roots (complete root system and 50 % rootsystem) and size of the cuttinge (large and small) and planting scheme (uniform or mixed cutting size) on the plant height three weeks after planting at the end of the long day period in a) Exp. 3 and b) Exp. 4 (means of three cultivars), a, b indicate significant differences between large and small cuttings.

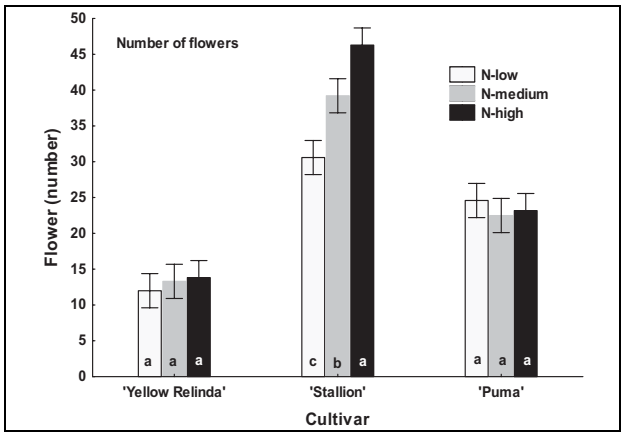


Fig. 4. Influence of cultivar and N concentration to cuttings on the number of flowers (Exp. 1).

numbers were reduced to 20 % those of large cuttings in the homogenous beds (Fig. 5b).

Influence of the cutting size and the root number of rooted cuttings on cultures without a long-day phase

To test the effect of a short-day culture on the quality of cut flowers, the same cultivars were cultivated in summer without a long-day phase (results not shown).

The omission of the long-day phase reduced the stem length by about 40 %, in line with expectations. The in-

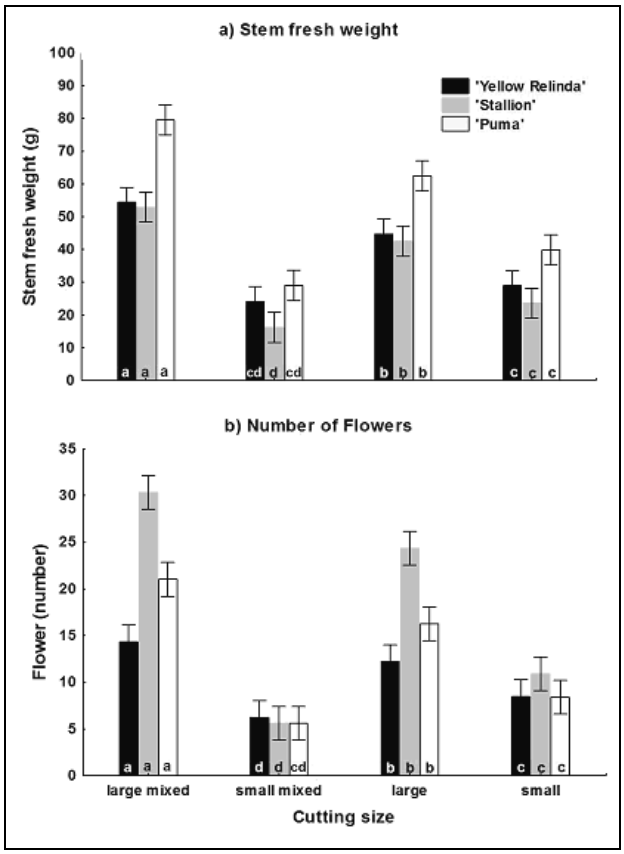


Fig. 5. Influence of cultivar, cutting size and the planting combination on a) the fresh stem weight and b) the numbers of flowers (Exp. 4).

fluence of small and large cuttings on the stem length was – analogous to the results of the culture with a long-day phase – significant, but small in absolute terms. Surprisingly, the flower numbers of the 'Puma weiß' and 'Stallion' cultivars fell by nearly 50 % without the long-day phase, while the flower numbers of 'Yellow Relinda' was virtually identical with the number from culture with a long-day phase.

As anticipated, the cutting size had an effect similar to that of the culture with a long-day phase; i.e., the stem weight and flower number of small cuttings were reduced by up to 50 % (depending on the cultivar). In heterogeneous beds with mixed populations of small and large rooted cuttings, the growth of small rooted cuttings remained below average, while large cuttings grew to above average sizes.

Influence of the root number

At the end of the long-day phase (three weeks after the plants in question had been planted), the root number had only a minor effect on the rate of growth with half and full number of roots and no significant difference was observed (Fig. 2). Also in Exp. 3 and 4 the root number had only a minor effect on the rate of growth, and no significant difference was observed at this stage of the experiment (Fig. 3). Reduced root number affected the final quality (Table 3). However, the effects were generally

small as shown for the stem fresh weight (Fig. 6a). Although the effect of root number on the cultivars 'Puma weiß' and 'Yellow Relinda' was most strong, the reduction in stem weight never exceeded 15 % or 12 g

When the combination of cutting size and mode of planting was tested in combination with reduction of roots in Exp. 4, the results confirmed the pre-dominant influence of cuttings size, which was further strengthened by mixed planting as shown for number of flowers (Fig. 6b). Again, the influence of root number was generally small but was more pronounced with large cuttings, particularly when those were growing in mixture with small cuttings (Fig. 6b).

Similar to the effect of a mixed planting of differently sized cuttings, a mixed planting of differently rooted cuttings promoted the limiting effects of root number on the quality of cut flowers. Thus, reduction of roots reduced the final stem fresh weight only when planted in mixture with cuttings with complete root system (Fig. 6c).

Discussion

The growth and external quality of cut chrysanthemums are determined by the cultivar, which is predominantly influenced by the season, the quantity of available light and also the temperature (LANGTON et al. 1999; LEE et al. 2002, 2003; PLOEG and HEUVELINK 2006). Models to assess the anticipated quality of cut chrysanthemums are essentially based on the influence of available light, bearing in mind the time when the cuttings were planted, the duration of the long days and the planting density (HEUVELINK et al. 2001). The duration of the long-day phase has a particularly strong influence on stem length. However, the present study was conducted to evaluate the effect of the quality of the starting material, in that case rooted cuttings on the subsequent development and final quality of cut flowers. Here, the most predominant influence was found for the cutting size. The effect of cutting size became even great, when plants of different quality experienced competition in a same flowerbed. Although larger cuttings, and consequently larger rooted cuttings, are capable of producing better rooting results in some species (DALAL et al. 2004; RAKESH 2005), even small rooted chrysanthemum cuttings became marketable cut stems. Nevertheless, the stem weight and flower number of small rooted cuttings fell short of the levels reached by larger rooted cuttings.

The results indicate, that the N status of the rooted cuttings (determined by the total N concentration of the cuttings) has only a small effect on the growth yield and quality of the cut flowers, at least when the culture is well managed (long-day phase, irrigation and high nutrient supply) and the original material (rooted cuttings for cut flowers and cuttings for potted cultures) is homogeneous. Nevertheless, the strong reduction of flowering of cultivar 'Stallion' by nitrogen deficiency in the cuttings (Fig. 3) indicates that depending on cultivar, there can be a sustainable influence of cutting quality on cut flowers. The influence of root number on yield and quality, significant as it was for two of the cultivars, was not substantial under these conditions (Exp. 1 and 2). Even in an extreme test version with only three roots (results not shown), the yield was only reduced by a maximum of 21 %. Thus, poorer quality chrysanthemum cuttings seem to be able to quickly compensate for such differences provided they receive the required supplies of water and nutrients. Such compensation following further growth occurred in both summer and winter, where no visual differences between plants could be observed. However, the slight difference that seemed to correlate with the N supply could serve to shorten the long-day phase and thereby the cultivation period by a few days. The Exp. 5, meanwhile, demonstrated that this only holds true for a homogeneous bed. When the flower bed was occupied by rooted cuttings of different qualities, existing differences were aggravated rather than reduced by further development (Fig. 6).

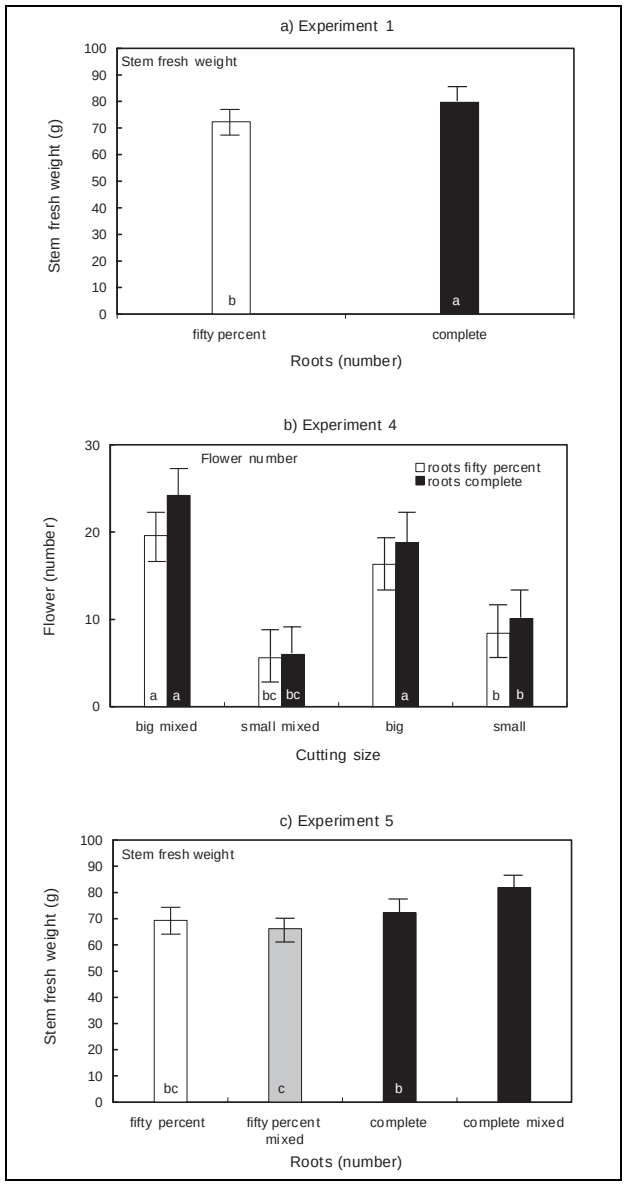


Fig. 6. Influence of a) root number on the fresh stem weight of cut flowers (means of three cultivars and three N-levels, Exp. 1), b) root number and cutting size in two different planting combinations in flower number and c) root number in two different planting combinations on stem fresh weight (means of three cultivars, Exp. 4 and 5).

Although the removal of roots may have temporarily changed the cytokinin content of the stems (FISEROVA et al. 2006), the effect is probably not sustainable for a longer period. We did not study the development of the root system after half the adventitious roots had been excised. It has to be considered that the further establishment of the root system, after excision of half the roots from an intensively rooted cutting, may differ when compared with an undisturbed, but initially poorly rooted cutting (SARANGA and CAMERON 2007). High planting density levels increase the competitive pressures on individual plants. Less well-developed plants are at a distinct disadvantage. Such competition in the flowerbed can have different effects. VOLIS and SHANI (2000) described a negative correlation between root number and distance to the neighbouring plant for a desert plant (*Eremobium aegyptiacum*). Other experiments have shown that the competition between individual corn plants is largely restricted to the generative phase and has a rather small influence on the vegetative growth stage (HASHEMI et al. 2005). The experiments with cut chrysanthemums have confirmed this.

It has to be concluded from this study, that uniform quality of rooted chrysanthemum cuttings, particularly in terms of shoot size but also of root number, is an important characteristic to provide synchronized growth and development and uniform final quality of chrysanthemum cut flowers

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