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CONTRACT REPORT

Bedding Plants: Growth Regulation by Mechanical Brushing

HDC PC 85a
1996

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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Date ...8 October 1996...

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HDC PC 85a

Bedding Plants: Growth Regulation by Mechanical Brushing

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RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

Application

Brushing was an effective technique for controlling petiole elongation in pansy transplants. Obtaining significant size control required only a small amount of brushing, the timing of the treatment was extremely flexible, and the treatments did not cause plant damage or delay flower production.

Summary

The commercial use of mechanical brushing, the physical movement of plants to control transplant growth, is quite limited. To be commercially successful, the technique must be simple and flexible, and must not reduce plant quality. Preliminary studies were conducted on four bedding plant species: pansy (*Viola tricolor*), geranium (*Pelargonium* x *hortorum*), impatiens (*Impatiens holstii*), and petunia (*Petunia hybrida*). Brushing was applied to seedlings growing in '165 plug trays' at a density of 1500 plants per m^2 using either polythene or plastic netting.

In two of the three pansy dose response experiments, increases in the number of brush strokes per day were accompanied by progressive reductions in petiole length. Ten or twenty brush strokes per day gave a significant reduction in petiole length (17 to 31% shorter than untreated plants) typically without significant effects on leaf area, dry weight or days to flower. Increasing the time interval between strokes by up to 10 minutes resulted in similar reductions as continuous brushing. There was no difference between brushing the plants at 0800 or 1600 hours, or between brushing once or twice per day. Plants required at least 5 days of treatment per week for effective size control. Brushing also gave a significant reduction in pansy petiole elongation in trials on a commercial holding.

For brushed geranium and impatiens, any reductions in plant stature were associated with significant plant damage. Vibrational stimulation of individual seedlings with a mechanical pollinator demonstrated that geraniums are responsive to mechanical stimulation, but a commercially viable method of stimulating either geranium or impatiens transplants was not identified.

Brushing induced a prostrate growth habit in petunia and significantly reduced leaf area and shoot dry weight. However, all of the brushing treatments resulted in noticeable leaf distortion.

Though brushing does not appear to be an appropriate method for controlling geranium, impatiens and petunia transplant size, it is a flexible, effective method for controlling petiole length in pansy without adversely affecting quality or long-term growth, and there appears to be great commercial potential for the use of this technique.

EXPERIMENTAL SECTION

INTRODUCTION

Plug transplants are typically grown at very high plant densities to make transplant production economically viable (Marr and Jirak, 1990). This close spacing can result in an uneven canopy of many elongated plants with weak stems. Delivering a crop of the correct size and proportions at the scheduled time can be extremely difficult. Control of bedding plant growth with chemical growth regulators is a common practice, but the use of these chemicals is expensive, difficult and increasingly restricted. There is, therefore, a commercial need for non-chemical treatments which decrease extension growth and improve crop uniformity.

Mechanical stimulation (MS), such as the shaking, flexing or rubbing of whole plants or plant parts, can decrease the rate of stem and petiole elongation in many species (Biddington, 1986; Latimer, 1991). One type of MS, brushing, is especially suited for commercial use, as it allows many plants to be stimulated at once. Despite extensive research, the commercial use of brushing to control transplant size remains limited. Brushing is used commercially on a limited scale to control the elongation of sugar beet (*Beta vulgaris*) transplants in Japan (Fletcher, 1984) and tomato (*Lycopersicon esculentum*) transplants in the United States (Björkman, personal communication). There is the potential to use this technology in more commercial operations if systems of brushing can be devised which are simple and flexible in their application, and which do not delay or decrease flower production.

Preliminary studies were conducted to determine whether four bedding plant species, pansy (*Viola tricolor*), geranium (*Pelargonium* x *hortorum*), impatiens (*Impatiens holstii*), and petunia (*Petunia hybrida*) are responsive to brushing, and if so, can brushing be used commercially to control the size of these species.

For those species for which the brushing treatments were successful, further experiments were conducted to determine the appropriate dosage and timing of brushing, and to characterise the amount, timing and number of days per week of brushing required for effective size control. Answers to these questions provided much of the information necessary for the successful utilisation of this technique at a commercial holding.

MATERIALS AND METHODS

Plant culture

Experiments were conducted using pansy ('Turbo Mix'), geranium ('Century Mix'), impatiens ('Accent Salmon' and 'Accent Mix'), and petunia ('Express Mid Blue' and 'Express Crimson Star') transplants provided by W.J. Findon & Sons, Stratford-upon-Avon. Plants were grown in '165 plug trays' at a density of 1500 plants per m^2. Plants were maintained in a glasshouse at HRI, Wellesbourne, at approximately 18 °C and were watered and fertilised with Vitafeed 19:19:19 (Vitax UK Limited, Leicester) as required. Supplementary lighting was only used in experiments conducted between 8 January and 16 February, 1996.

Treatment application and experimental design

Materials were folded over and secured at the loose end to make the brushing apparatus. Brushing was applied by stroking the canopy back and forth with these materials (Appendix 1, Plate 1), and each back and forth movement was counted as a single brush stroke. Treatments were arranged in either a randomised complete block design or a completely randomized design, with a quarter tray used as an experimental unit. Guard rows one to two cells wide surrounded all experimental units, so that edge plants were not sampled. Treatments were begun at the cotyledon stage of growth and continued until the plants were of a saleable size, typically after 25 to 30 days of treatment. Details regarding the design, number of replications and cultivar used in each experiment, and the time period during which each experiment was conducted are listed in Appendix 2.

Preliminary experiments

Determining the appropriate material for brushing

Flexible materials, including polythene (LBS Polythene, Lancashire) and two gauges of plastic netting (Bradley Lomas Electrolok, Ltd., South Yorkshire), were used to provide the brushing stimulus, as such materials are more easily integrated with production practices. Experiments were conducted with each of the four species to identify a material which could provide an effective amount of stimulation without damaging the plants.

Determining the appropriate amount of brushing

Further experiments were conducted on those species for which an appropriate material for brushing was found (pansy and petunia). Plants were brushed 10, 20, or 40 times back and forth, once a day to determine the appropriate dosage of brushing. A control treatment that was not brushed was also included.

Brushing only provided successful size control with minimal plant damage to pansy transplants. Experiments were conducted therefore to examine more closely the relationship between the number of brush strokes per day and size reduction in pansy and, if possible, to determine an optimum dosage. Pansy plants received 5, 10, 20, 30 or 40 brush strokes each morning, or were left untreated.

Determining responsiveness to MS

It was not possible to control geranium and impatiens transplant size with brushing without causing severe and noticeable damage. As not all plant species are responsive to MS (Jaffe, 1973), it was unknown whether geraniums and impatiens were insensitive to MS, or if a method of non-injurious stimulation had yet to be identified for these species. Therefore, a set of experiments was conducted to determine whether these two species are responsive to MS.

One tray each of geranium and impatiens transplants were obtained, and the plants in one half of each tray were left untreated. In the other half of each tray, plants were individually stimulated for approximately 10 seconds daily with a mechanical tomato pollinator (Brinkman UK, Ltd., Humberside) at the lowest possible setting.

The pollinator was chosen as a means of providing MS because it can provide a consistent level of mild vibrational stimulation. Also, as this equipment is designed for use on delicate tomato flowers, it was assumed that careful use of the pollinator would not cause injury to the transplants. However, the leaves of impatiens transplants were often injured by the stimulation. Treatments on impatiens were discontinued and no measurements were taken for this species. Geranium transplants were stimulated without injury, and petiole lengths were measured after 13 days of stimulation and were analyzed using a two-sample t test. The few plants which had noticeable damage (perhaps due to mishandling of the pollinator), were not included in the measured sample.

Further experiments with pansy

Interval between brush strokes

To determine whether the time interval between brush strokes could be increased and still result in the same amount of size control for pansy transplants as continuous brushing, two experiments were conducted in which the total daily stimulation remained constant, but the time interval between strokes was varied. Plants were either untreated, brushed continuously, or were brushed with a 1 or 10 minute interval between paired back and forth strokes. A total of 20 brush strokes per day was applied in the first experiment, and 10 or 20 strokes per day in the second experiment.

Time of day

Two experiments were conducted to determine the most appropriate time of day for the effective brushing of pansy transplants. Plants were either untreated, or were brushed in the morning (at approximately 09:00), in the afternoon (at approximately 16:00) or twice a day (half in the morning and half in the afternoon). The total number of strokes was the same for each treatment (20 per day in the first experiment, and 10 per day in the second experiment).

Times per week

It would be commercially beneficial if transplants did not have to be brushed every day to maintain control of petiole elongation. Therefore, experiments were conducted in which pansy plants were either untreated or were brushed in the morning each day, five days a week (Monday to Friday, inclusive), or every other day. Twenty brush strokes per day were applied in the first experiment and 10 strokes per day in the second experiment.

Commercial trials

A series of commercial trials were conducted at W.J. Findon & Sons nursery starting 12 July 1996. During three separate production runs, a bench (42 trays) of pansy ('Universal Plus Mixed') transplants growing in '350' plug trays was used to test the effectiveness of brushing. Plants were maintained according to standard production practices, except chemical growth regulators were not applied. Half of the plants (21 trays) were brushed with a large modified version of the brushing apparatus used at HRI (Appendix 1, Plate 2). Treatments began nine days after seeding and continued until the plants were dispatched approximately five weeks later. Plants were typically brushed continuously once a day every morning. Plants received ten strokes per day during the first three to ten days of treatment, and then the dose was gradually increased over time until the final daily dose was 20 or 30 brush strokes per day. Survival counts were taken at the gapping up stage, and at the end of the treatment period petioles of 30 randomly sampled plants from each treatment were measured.

Data collection and analysis

At the end of all brushing experiments conducted at HRI, the petiole length and shoot dry weight of ten sampled plants per plot were measured, and any damage noted. Leaf area and the number of leaves per plant were also recorded for many experiments. A portable chlorophyll meter (SPAD-502, Minolta), which estimates chlorophyll content by comparing light transmission at two wavelengths (Schaper and Chacko, 1991), was used to determine changes in pansy leaf colour. During the last set of pansy experiments (conducted between 14 May and 10 June, 1996), shade screens were used to prevent leaf damage on sunny days.

Data were analyzed using analysis of variance, the Chi-square test of homogeneity and Fisher's protected LSD with 95% confidence (MINITAB, 1995).

RESULTS

Pansy

Preliminary experiments

Problems were encountered when certain materials were used to brush pansy transplants. Polythene could not be applied uniformly across the plant canopy and plants brushed with small gauge netting were characterised by leaf damage. However, brushing with 20/20 gauge netting was successful. Pansy petiole length was decreased by brushing without causing leaf damage or significant reductions in leaf area or biomass accumulation (Table 1). This netting was used for brushing in all other pansy experiments.

Table 1. The effect of brushing with several different materials on pansy transplant size.

Material for brushing	Petiole length (mm)	Leaf area (cm^2)	Shoot dry weight (mg)	Root dry weight (mg)	Root to shoot ratio
untreated	13.2	12.6	77	19	0.25
polythene	11.7	12.9	84	22	0.26
small netting	10.6	11.3	77	17	0.22
20/20 netting	11.8	12.1	79	18	0.23
F test	*	*	*	*	NS
SE	0.52	.44	2.9	1.0	0.012
$LSD_{0.05}$ (9 df)	1.49	1.03	5.5	3.0	-

NS, * Main effects within column not significant at $P = 0.05$ or significant at $P < 0.05$, respectively.

During the initial dosage experiment, in which plants received 10, 20 or 40 brush strokes per day, petiole length was significantly reduced by all three brushing treatments and a significant linear relationship was shown between petiole length and the number of brush strokes per day (Figure 1).

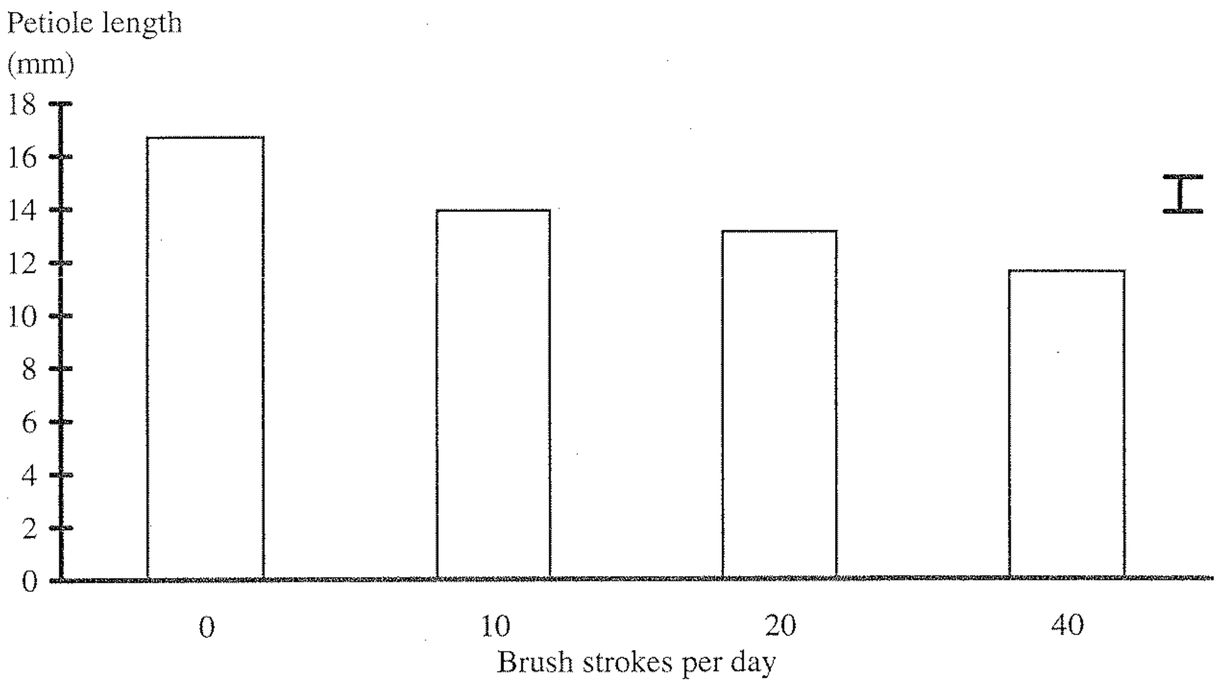


Fig 1. The effect of brushing on pansy petiole length (first dosage experiment). There is a significant linear trend between the number of brush strokes per day and the final petiole length. The bar indicates Fisher's protected LSD based on 9 error degrees of freedom with 95% confidence level.

On average, the treated plants had a significantly lower leaf area than untreated plants but there was no significant relationship with the number of strokes (Table 2). Use of the chlorophyll meter demonstrated that the leaves of treated plants were significantly greener than those of untreated plants, and that there was a significant linear relationship between the number of brush strokes per day and the optical density of the leaves. Leaf number did not appear to be decreased by the treatments (Appendix 3).

Table 2. The effect of the number of brush strokes per day on the growth of pansy transplants (initial dosage experiment).

Brush strokes	Leaf area (cm^2)	SPAD reading†	Shoot dry weight (mg)	Root dry weight (mg)	Root to shoot ratio
none	11.7	36	70	16	0.23
10	9.9	38	63	-	-
20	10.0	39	63	12	0.19
40	8.6	40	55	-	-
F tests:					
overall	*	***	*	NS	NS
brushed v. untreated	**	***	*	-	-
linear	NS	*	NS	-	-
SE	0.51	0.6	2.6	1.5	-
$LSD_{0.05}$ (9 df)	1.71	1.3	9.5	-	0.020

NS, ***, **, * Main effects within column not significant at P = 0.05 or significant at P < 0.001, 0.01 or 0.05, respectively. There were no significant quadratic trends.
† For explanation see text.

The treatments also resulted in a significant reduction in shoot dry weight as compared to untreated plants. There was a slight, but not significant, linear trend between the number of brush strokes per day and shoot dry weight, with 40 strokes per day resulting in the largest reduction. Twenty strokes per day caused a decrease in root dry weight, but this difference was not significant and did not affect the root to shoot ratio.

Plants which had been brushed 20 times per day, but which had not been sampled for dry weight, were potted up and brushing was discontinued. The onset of flowering was not delayed, the number of days to fifty percent flower was the same as that for untreated plants (Appendix 4A), and flowers did not appear to be damaged.

Two more experiments were conducted to determine an optimum dosage level for brushing pansy transplants. In both of these experiments, the petiole length and shoot dry weight of treated plants were significantly less than those of unbrushed plants (Table 3). There were no significant differences between the five brushing treatments for either variate in the first experiment. However, in experiment two, a significant linear relationship was shown, with reductions in petiole length and shoot dry weight as the number of brush strokes increased. Leaf colour was not affected by any of the treatments (Appendix 5).

Table 3. The effect of the number of brush strokes per day on the growth of pansy transplants, (additional dosage experiments).

Brush strokes per day	Petiole length (mm)		Shoot dry weight (mg)	
	Experiment		Experiment	
	1	2	1	2
none	12.8	20.2	59	80
5	10.0	17.4	52	75
10	9.3	15.0	50	63
20	9.6	14.0	51	62
30	10.1	13.3	45	49
40	9.8	12.8	50	54
F tests: overall	**	***	NS	***
brushed v. untreated	***	***	*	***
linear trend	NS	**	NS	***
SE	0.55	0.85	4.1	4.1
$LSD_{0.05}$ (18 df)	1.62	2.51	-	12.3

NS, ***, **, * Main effects within column not significant at P = 0.05 or significant at P < 0.001, 0.01 or 0.05, respectively. There were no significant quadratic trends.

Though 5 strokes per day did cause a statistically significant decrease in petiole length in both experiments, the stimulus was judged to be insufficient to be of practical importance to the grower. In experiment two, for example, 5 brush strokes per day resulted in a decrease in petiole length of only 14%.

In both experiments, 30 or 40 brush strokes per day caused noticeable plant damage and in experiment two, resulted in a substantial reduction of shoot dry weight without a proportionally large improvement in petiole length reduction.

Further experiments

Time Interval between Strokes

In both experiments, brushing significantly reduced petiole length, but there were no significant differences between the three brushing treatments (Table 4). Shoot dry weight was not significantly affected by brushing and there was no noticeable damage in either experiment. Treated plants were significantly more green than untreated plants in both experiments (Appendix 5). More importantly, contrasts between continuous and non-continuous brushing and between 1 and 10 minute intervals were not significant for any measured variate in either experiment.

Time of Day

Petiole length, leaf area and shoot dry weight were all significantly decreased by brushing, though there were no significant differences between the three brushing treatments for any of these variates (Table 5). The number of leaves per plant appeared independent of the time of day of brushing in both experiments (Appendix 3) and there was no significant change in leaf colour (Appendix 5) or noticeable damage in either experiment. Furthermore, contrasts between the morning and evening treatments and between one and two treatment applications per day were not significant for any measured variate in either experiment.

Table 4. The effect of varying the time interval between paired brush strokes on the growth of pansy transplants.

Method of brushing	Petiole length (mm)		Shoot dry weight (mg)	
	Experiment		Experiment	
	1	2	1	2
none	12.2	18.5	63	65
continuous	10.0	17.1	60	71
1 minute intervals	9.5	16.3	54	70
10 minute intervals	9.6	16.1	56	64
F tests: overall	**	NS	NS	NS
brushed v. untreated	***	*	NS	NS
continuous v. non-continuous	NS	NS	NS	NS
1 v. 10 minute interval	NS	NS	NS	NS
SE	0.47	0.92	2.8	4.1
$LSD_{0.05}$ (15 df)	1.57	-	-	-

NS, ***, **, * Main effects within column not significant at $P = 0.05$ or significant at $P < 0.001$, 0.01 or 0.05, respectively.

Table 5. The effect of time of day of brushing on the growth of pansy transplants.

Time and frequency of daily brushing	Petiole length (mm)		Leaf area (cm^2)		Shoot dry weight (mg)	
	Experiment		Experiment		Experiment	
	1	2	1	2	1	2
none	15.4	18.6	12.4	15.6	80	88
morning only	12.8	16.1	10.3	11.9	70	70
afternoon only	12.3	15.6	10.5	12.6	72	73
morning & afternoon	12.0	16.6	10.6	13.4	73	77
F tests: overall	***	**	**	*	NS	*
brushed v. untreated	***	**	**	**	*	**
morning v. evening	NS	NS	NS	NS	NS	NS
1 v. 2 applications per day	NS	NS	NS	NS	NS	NS
SE	0.45	0.76	.53	.74	3.5	4.0
$LSD_{0.05}$ (15 df)	1.15	1.64	1.12	2.32	-	11.6

NS, ***, **, * Main effects within column not significant at P = 0.05 or significant at P < 0.001, 0.01 or 0.05, respectively.

Times per Week

Treated plants typically had significantly shorter petioles than untreated plants (Table 6). In experiment one, there was a significant inverse linear relationship between petiole length and the number of times per week that the plants were treated. Brushing every other day was the only treatment that did not provide a sufficient or significant decrease in petiole length relative to unbrushed plants. A similar trend was noted for the petiole length data in experiment two, though this trend was not significant. There was a significant inverse relationship between both the leaf area and shoot dry weight and the number of times per week that the plants were brushed in experiment one. The leaf area and shoot dry weight were not significantly affected by any of the brushing treatments in experiment two. The number of leaves per plant seemed independent of the brushing treatments in both experiments (Appendix 3). The greenness of the leaves was only significantly increased in experiment two when plants were brushed five or seven days per week (Appendix 5). There was no noticeable plant damage in either experiment.

Table 6. The effect of the frequency of brushing per week on the growth of pansy transplants.

Frequency of brushing	Petiole length (mm)		Leaf area (cm^2)		Shoot dry weight (mg)	
	Experiment		Experiment		Experiment	
	1	2	1	2	1	2
none	12.4	16.8	9.3	13.4	65	80
alternate days	11.5	15.4	8.3	12.0	61	75
5 consecutive days per week	10.4	14.4	7.8	10.6	56	68
every day	9.6	14.2	7.1	11.7	53	75
F tests: overall	***	NS	***	NS	***	NS
brushed v. untreated	***	NS	***	NS	***	NS
linear trend†	**	NS	**	NS	***	NS
SE	0.35	0.90	.27	.84	2.1	4.2
$LSD_{0.05}$ (15 df)	1.06	-	.67	-	4.0	-

NS, ***, ** Main effects within column not significant at P = 0.05 or significant at P < 0.001 or 0.01, respectively. There were no significant quadratic trends.
† Based on brushing an average of 3.5, 5 or 7 days per week.

Flowering

Pansy plants from experiments conducted between 27 March and 2 May which had been brushed continuously 20 times per day, 7 days per week, were potted up and brushing discontinued. The treatments did not result in a delay to the onset of flowering, an increase in the number of days to fifty percent flower as compared to untreated plants (Appendix 4B), or damaged flowers.

Commercial trials

In two of the three trials, treated plants were visibly smaller than those that were not brushed (Appendix 1, Plate 4), and the treatments resulted in a highly significant decrease in petiole length as compared to untreated plants (24-25% shorter), but were not as small as those receiving weekly growth regulator applications (approximately 50% shorter than unbrushed plants).

Geranium

Treatments did not begin until after the geranium seedlings had reached the first true leaf stage, as they were not sufficiently rooted before this time. In the first experiment, all of the brushing treatments (20 or 40 brush strokes per day) reduced petiole length but also caused plant damage and typically resulted in highly significant reductions in leaf area and shoot dry weight (Table 7). When a dose of 10 or 20 brush strokes per day were used in another experiment, brushing with flexible materials such as plastic netting did not cause noticeable stem or petiole flexure and did not have a significant effect on plant petiole length (Fig. 2a) or shoot dry weight (Fig. 2b). The number of leaves per plant (Appendix 3) was also unaffected by the treatments. Therefore, plants were also brushed with cardboard, which did cause stem and petiole flexure. Those treatments which significantly reduced plant size also resulted in leaf damage or dislodged the plants from the compost.

However, geranium petiole length was significantly reduced without noticeable injury by stimulation with the tomato pollinator. Petioles of treated geranium plants were 21% shorter than those of untreated plants (t test $(\mu_1-\mu_2) > 0$ significant at $P < 0.001$). A suitable means of utilising this response on a large scale has yet to be identified.

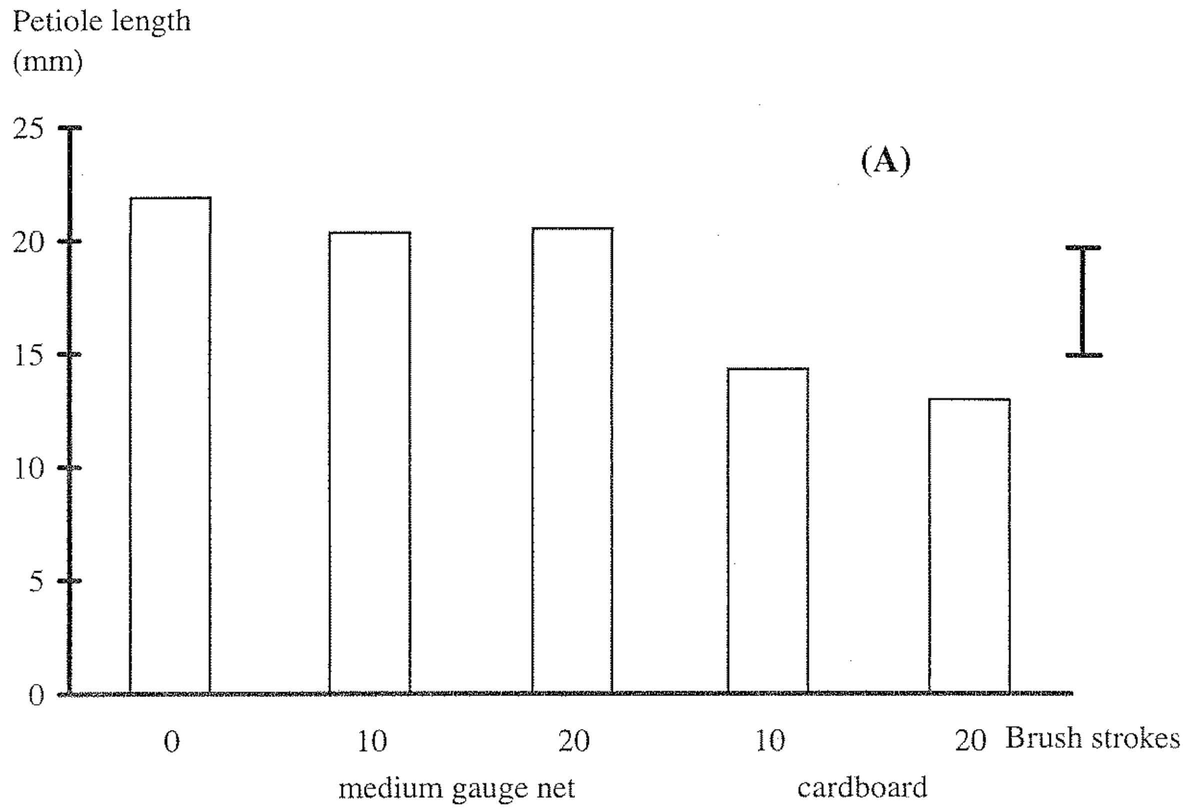
Table 7. The effect of high doses of brushing with different materials on geranium transplant growth.

Treatment	Petiole length (mm)	Leaf area (cm^2)	Shoot dry weight (mg)
untreated	20.2	19.7	160
netting 20†	16.9	19.4	170
netting 40	13.9	14.0	132
cardboard 20‡	13.1	14.0	129
F test	*	*	**
$LSD_{0.05}$ (8 df)	4.55	4.52	16.9

**, * Main effects within column significant at $P < 0.01$ or 0.05, respectively.
† Indicates the number of brush strokes applied per day.
‡ Plants brushed with cardboard 40 times per day were not included in the analysis because the survival rate was too low to obtain an accurate sample size.
Note that all treated plots were characterised by damaged plants.

Impatiens

Brushing with plastic netting resulted in significant reductions in stem length (Table 8). However, this reduction was accompanied by noticeable leaf damage and highly significant reductions in leaf area and shoot dry weight, but without a reduction in leaf number per plant (Appendix 3). Impatiens transplants brushed with polythene were not damaged, but differences from untreated plants in stem length, leaf area and shoot dry weight were not typically significant. Also, transplants stimulated with the pollinator had noticeable leaf damage before the experiment was discontinued.



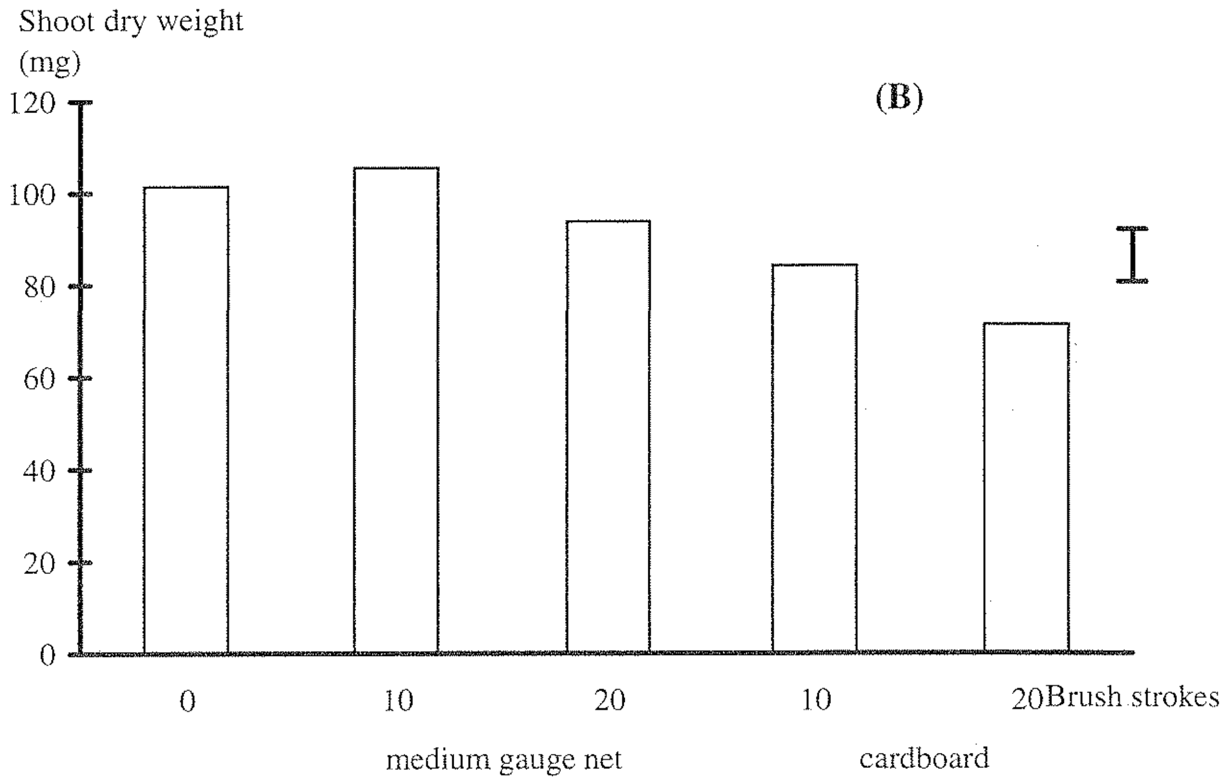


Fig 2. The effect of brushing on geranium (**A**) petiole length and (**B**) shoot dry weight. Plants treated with cardboard were characterised by severe plant damage. The bar indicates Fisher's protected LSD based on 15 error degrees of freedom with 95% confidence level.

Table 8. The effects of brushing with different materials on impatiens transplant growth.

Experiment	Stem length (mm)	Leaf area (cm^2)	Shoot dry weight (mg)
20 brush strokes per day			
untreated	26.2	8.4	66
polythene	25.8	8.2	65
small netting	23.6	6.4	47
20/20 netting	23.0	7.0	46
F test	*	***	***
$LSD_{0.05}$ (9 df)	2.46	0 .76	8.9
20 brush strokes per day			
untreated	27.4	-	42
polythene	26.5	-	38
small netting	20.3	-	26
20/20 netting	21.6	-	30
F test	***	-	***
$LSD_{0.05}$ (15 df)	2.36	-	3.2
10 brush strokes per day			
untreated	28.9	-	43
polythene	29.2	-	39
small netting	24.9	-	35
20/20 netting	24.6	-	33
F test	*	-	*
$LSD_{0.05}$ (9 df)	3.38	-	5.6

***, * Main effects within column significant at $P < 0.001$, or 0.05, respectively.
Note that plants brushed with netting were characterised by visible leaf damage, even in the experiment with only 10 brush strokes per day.

Petunia

Brushing with a variety of materials resulted in smaller, more prostrate transplants relative to those which were untreated, but these differences were difficult to measure due to the rosette growth habit of the plants. Changes in size were therefore determined by leaf area and shoot dry weight measurements. It was difficult for brushing to be applied uniformly with polythene, and the small netting caused leaf damage. However, petunia plant size was noticeably and significantly decreased by brushing with 20/20 gauge plastic netting (Table 9) without leaf damage.

Table 9. The effect of the number of brush strokes per day on the growth of petunia transplants.

	Material used for brushing				F test	SE	$LSD_{0.05}$ (9 df)
	untreated	polythene	small netting	20/20 netting			
Leaf area (cm^2)	16.8	15.6	13.9	15.4	*	0.87	1.90
Shoot dry weight (mg)	91	84	78	79	NS	4.0	-

NS, * Main effects within column not significant at P = 0.05 or significant at P < 0.05, respectively.

An experiment was conducted to determine the appropriate dosage level for brushing with this material. All three treatments (10, 20 or 40 strokes per day) caused leaf distortion (Appendix 1, Plate 4) and significant reductions in leaf area and shoot dry weight, but there were no significant differences between the three treatments for either variate (Table 10). Twenty brush strokes per day also significantly decreased root dry weight relative to untreated plants, but did not significantly affect the root to shoot ratio. The number of leaves per plant did not appear to be affected by the treatments (Appendix 3). Plants which had been brushed 20 times per day, but which had not been sampled for dry weight, were potted up and brushing was discontinued. The rate of flowering of brushed plants was significantly less then that of untreated plants and the brushed plants reached 50% flower 3 to 4 days after untreated plants (Appendix 4C).

Table 10. The effect of the number of brush strokes per day on the growth of petunia transplants.

Brush strokes	Leaf area (cm^2)	Shoot dry weight (mg)	Root dry weight (mg)	Root to shoot ratio
none	8.0	24	10	0.41
10	6.8	21	-	-
20	6.2	19	7	0.37
40	6.2	20	-	-
F tests:				
overall	**	*	**	NS
brushed v. untreated	**	**	-	-
linear	NS	NS	-	-
SE	0.35	1.2	0.8	0.020
$LSD_{0.05}$ (9 df)	0.97	2.8	1.0	-

NS, **, * Main effects within column not significant at P = 0.05 or significant at P < 0.01 or 0.05, respectively. There were no significant quadratic trends.

DISCUSSION

Pansy

It was possible to reduce significantly the petiole length of pansy plants without causing noticeable leaf damage or distortion. The optimum daily dosage appeared to be approximately 10 to 20 brush strokes. This amount of brushing consistently resulted in a 17 to 31% decrease in petiole length relative to unbrushed plants, without a substantial decrease in leaf area or biomass accumulation, or increase in days to flower. The plants were not noticeably damaged by brushing, and the treatments may serve to increase marketability by intensifying the green coloration of the leaves. In a commercial setting, the amount of daily brushing could be reduced if environmental conditions are such as to prevent rapid petiole elongation, so that only as much brushing is applied as is necessary to control transplant size.

The results of the experiments on increasing the time interval between strokes were consistent with those from similar experiments using tomato transplants (Garner and Björkman, 1996). For both species, the time interval between strokes can be at least 10 minutes long, and still result in the same amount of size control as continuous stimulation. It is not necessary for pansy plants to receive daily brushing in a series of continuous strokes. This provides flexibility for commercial application, especially if the technique is to be automated.

The effectiveness of brushing was not significantly influenced by the time of day of its application. In commercial practice, the timing of brushing pansy transplants should be extremely flexible. There were no statistical differences between treating the plants in the morning or the afternoon, or treating them once or twice a day. The choice of the best time of day for brushing can be left to the individual grower, and could even be determined on a daily basis to minimise interference with production practices and to avoid brushing the plants when they are either wilting or wet.

The results of the experiments on the number of treatments per week demonstrated that some reduction in the frequency of brushing can be tolerated. In experiment one, brushing for only five days per week provided a significant decrease in petiole length while minimising reductions in leaf area and shoot dry weight. Whilst brushing at least once a day has been recommended for the height control of tomato and cucumber (*Cucumis sativus*) transplants (Latimer, 1992), this may not be necessary for pansy transplants.

All of these experiments on pansy transplants provided the information necessary to begin commercial trials, and the results obtained during such trials were consistent with those obtained in controlled experiments at HRI. Furthermore, significant reductions in petiole elongation were given during commercial trials, despite the fact the plants were sometimes brushed at different times of the day, or were not brushed at all on some days to avoid conflicts with production and labour schedules. It seems that the most likely use for brushing will be to reduce the use of growth regulators, as opposed to replacing them altogether, especially during the summer, when problems of rapid petiole elongation are considerable.

Geranium

It was not possible to reduce significantly geranium transplant size by brushing without causing plant damage. Geranium petiole length was, however, significantly reduced by daily stimulation with a tomato pollinator. Though a pollinator or similar device is not a viable alternative for providing MS on a commercial scale, its use here demonstrates that geranium plants are responsive to MS. Geranium petiole length can be reduced by MS without causing noticeable transplant damage. However, a commercially viable means of imparting this stimulation without causing damage has not yet been identified.

Impatiens

It was not possible to mechanically stimulate impatiens transplants without causing damage. It is therefore still unknown whether impatiens are responsive to MS. However, if impatiens are sensitive to MS, it seems unlikely that the level of brushing necessary to provide significant height reduction can be applied without causing noticeable injury. Impedance, the restriction of stem elongation by a physical barrier, is another option for investigating whether impatiens are sensitive to MS. Perhaps a small glasshouse experiment could be conducted, during which plants are impeded overnight. Regardless of whether this treatment could be used commercially, such an experiment would help to determine whether future experiments regarding the use of MS to control transplant height of impatiens are warranted.

Petunia

The effects of brushing on the leaf area and shoot dry weight of petunia transplants were substantial and significant. These differences may have been caused by a twisting and bending of the leaves, which was observed even at the lowest dosage level. Leaves appeared "normal" 4 to 5 days after brushing was discontinued. However, this deformation is unlikely to be commercially acceptable, despite the relatively short recovery time. New methods of brushing for petunias should be investigated.

CONCLUSIONS

The commercial adaptation of brushing for pansy transplants appears promising. Though problems were encountered when attempting to brush geranium, impatiens and petunia transplants, it was possible to significantly decrease pansy petiole length without reducing plant quality. It is concluded that brushing pansy transplants is a sufficiently flexible technique to be integrated with commercial production practices. Pansy transplants require only a small amount of daily stimulation, and the dosage can be adjusted to suit the growth rate of the crop. The timing of the stimulation is not critical. Plants can be brushed at a time when the grower finds it most convenient, and brushing does not have to be applied continuously. Plants do not have to be brushed every day, although treatment on at least five days per week is likely to be necessary for effective size control. The response of plants to MS varies with species, but this and other work consistently shows that the magnitude of the response to MS is not greatly affected by altering the dosage or timing of the stimulation. The use of this technique in conjunction with growth regulator applications is now being investigated at W.J. Findon & Sons. Our research also suggests that this technique is also flexible enough to be utilised at other commercial facilities.

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Appendix 1. Photographic plates

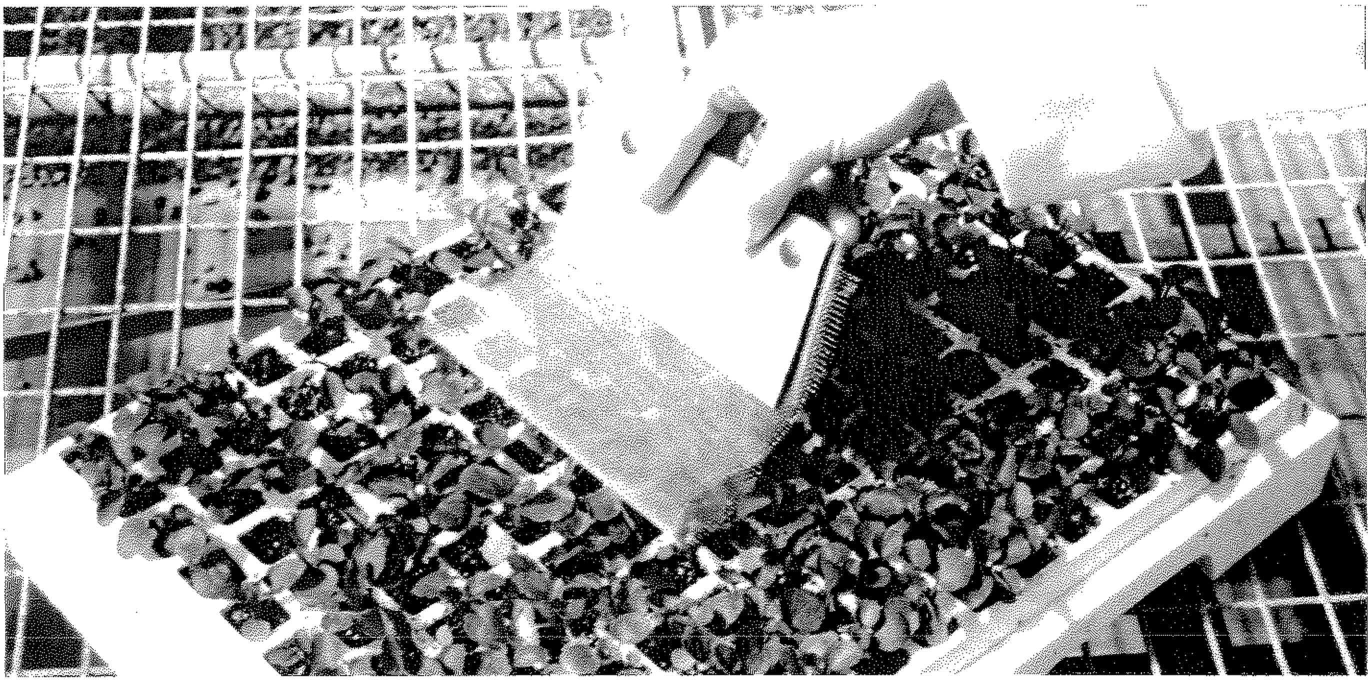


Plate 1. Brushing apparatus as used in many experiments at HRI.

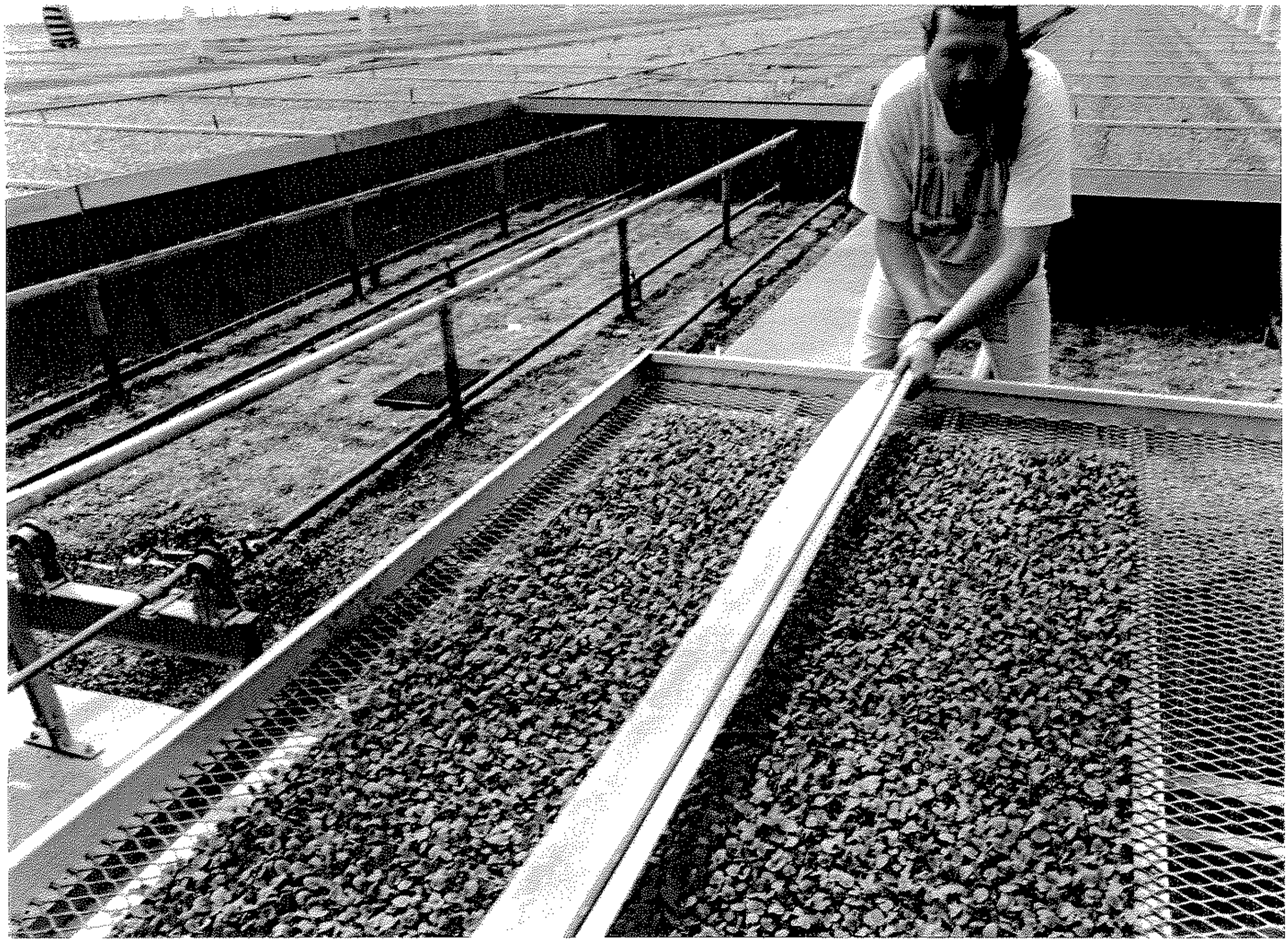


Plate 2. Brushing apparatus as used in commercial trials.

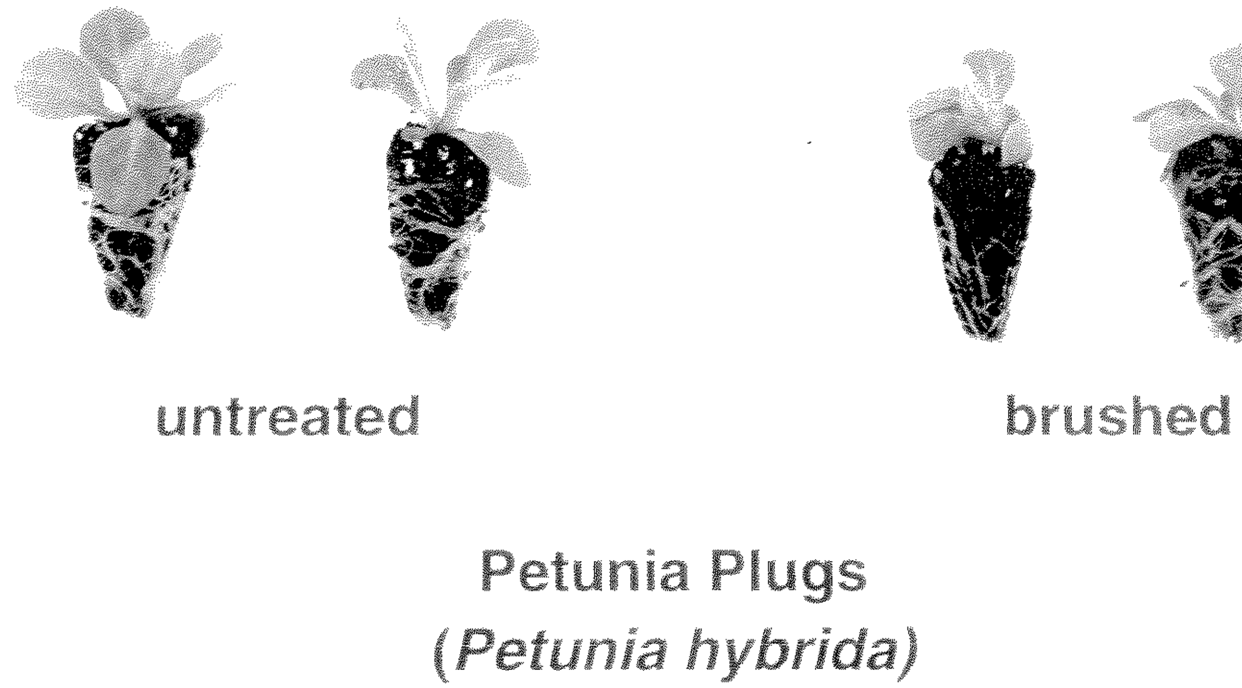


Plate 3. The effects of brushing on petunia transplant growth. Note that all brushing treatments induced a prostrate growth habit and caused leaf distortion that was not observed in unbrushed plants.

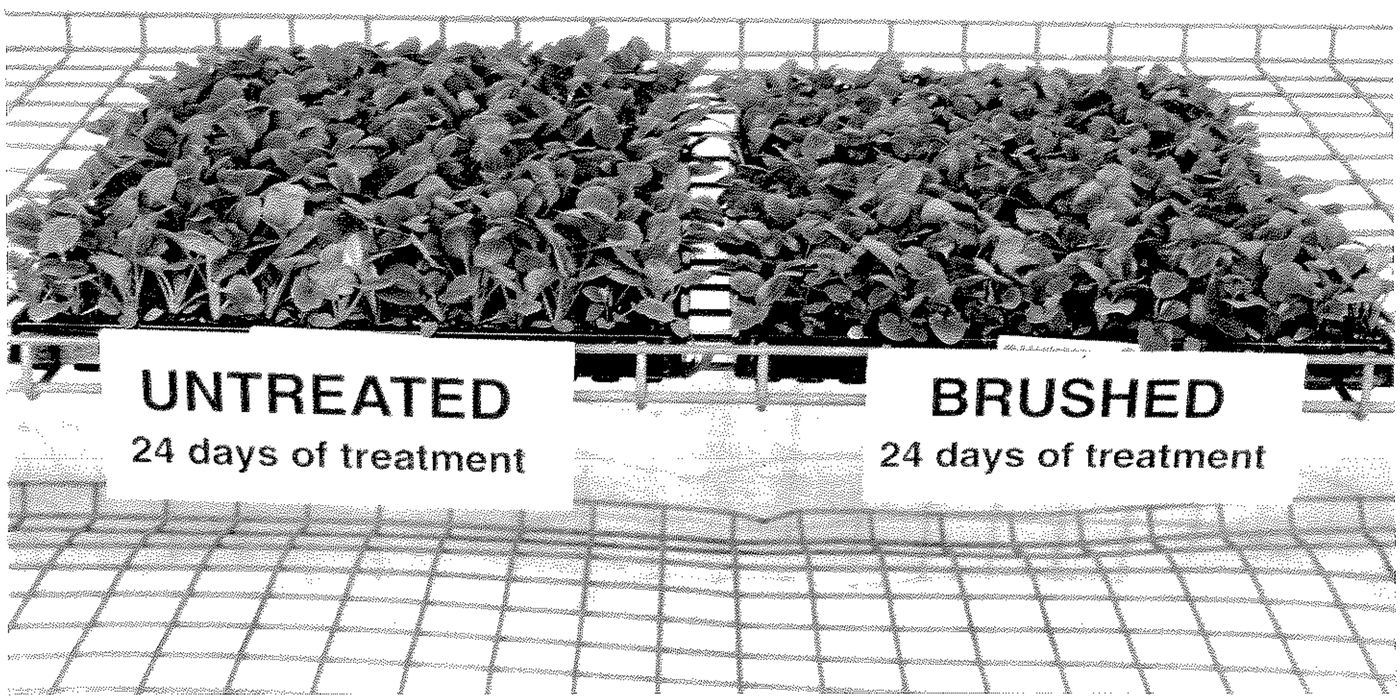


Plate 4. The effect of brushing on pansy transplant size in commercial trials.

Appendix 2. Experiments conducted at HRI

Species	Cultivar	Design or analysis	n	Dates (1996)	Investigation
Pansy	'Turbo Blue-white Bicolour'	RCBD	4	8/1 - 9/2	material
	'Turbo Mix'	RCBD	4	2/2 - 13/3	dosage
	'Turbo Mix'	CRD	4	27/3 - 28/4	dosage
	'Turbo Mix'	CRD	4	14/5 - 8/6	dosage
	'Turbo Mix'	RCBD	6	27/3 - 30/4	time interval
	'Turbo Mix'	RCBD	6	14/5 - 8/6	time interval
	'Turbo Mix'	RCBD	6	27/3 - 2/5	time of day
	'Turbo Mix'	RCBD	6	14/5 - 9/6	time of day
	'Turbo Mix'	RCBD	6	27/3 - 30/4	times per week
	'Turbo Mix'	RCBD	6	14/5 - 10/6	times per week
Geranium	'Century Mix'	CRD†	3	8/1 - 5/2	material
	'Century Mix'	CRD	4	2/2 - 5/3	material (lower dose)
	'Century Mix'	t-test	23	16/4 - 3/5	sensitivity to MS
Impatiens	'Accent Salmon'	RCBD‡	4	8/1 - 6/2	material
	'Accent Salmon'	RCBD	6	2/2 - 4/3	material
	'Accent Salmon'	RCBD	4	2/2 - 4/3	material (lower dose)
	'Accent Mix'	t-test	N/A	16/4 - 23/4	sensitivity to MS
Petunia	'Express Mid Blue'	RCBD	4	8/1 - 9/2	material
	'Express Crimson Star'	RCBD	4	2/2 - 7/3	dosage

† Completely randomised designed
‡ Randomised complete block design

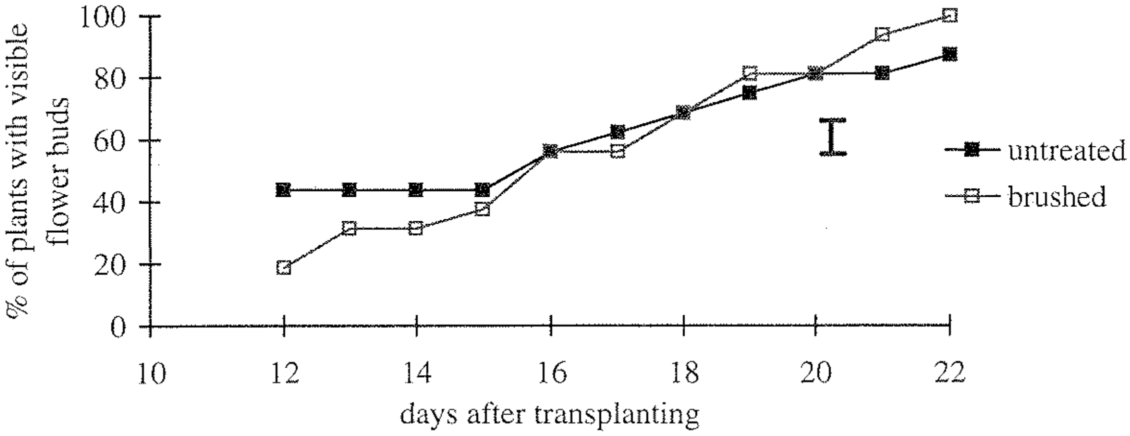
Appendix 3. The effect of brushing on the final number of leaves.

Species	Treatment	Leaves per plant	χ^2	df	P-value
Pansy	untreated	5.0	10.70	6	NS
	plastic	5.3			
	small netting	5.0			
	medium netting	5.1			
Pansy	untreated	5.1	12.53	6	NS
	10	5.0			
	20	5.0			
	40	4.8			
Pansy	untreated	5.4	6.66	6	NS
	morning	5.2			
	evening	5.3			
	both	5.4			
Pansy	untreated	5.5	11.58	6	NS
	morning	5.0			
	evening	5.2			
	both	5.2			
Pansy	untreated	5.0	6.29	6	NS
	every day	4.8			
	5 days per week	4.7			
	every other day	4.8			
Pansy	untreated	5.3	4.52	6	NS
	every day	5.3			
	5 days per week	5.0			
	every other day	5.1			
Geranium	untreated	3.9	6.42	3	NS
	netting/20	3.9			
	netting/40	3.6			
	cardboard/20	3.5			
Impatiens	untreated	5.1	15.97	6	*
	plastic	5.5			
	small netting	4.8			
	medium netting	5.0			
Petunia	untreated	6.2	7.39	6	NS
	10	6.3			
	20	6.4			
	40	6.7			

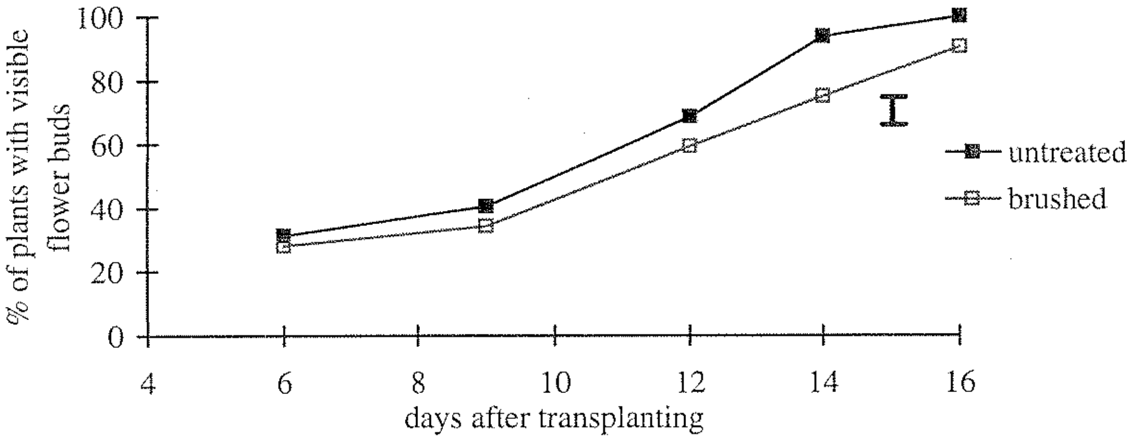
NS, * Not significant or significant at $P = 0.05$, respectively.

Appendix 4. The effect of brushing on the flowering of transplanted pansy and petunia plants.

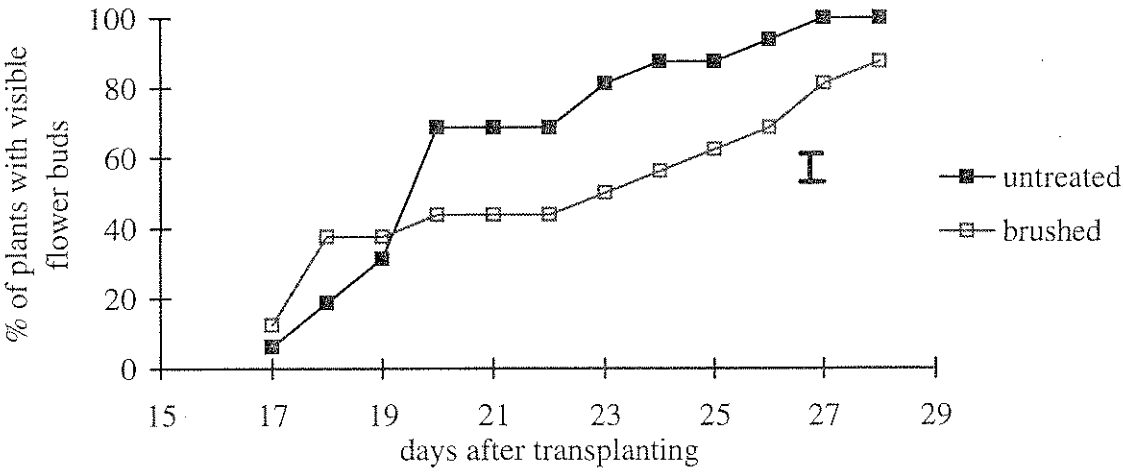
A. Pansy (plants from first dosage experiment)



B. Pansy (plants from first experiments on the timing of brushing)



C. Petunia (plants from dosage experiment)



Bars represent the standard error of the mean.

Appendix 5. The effect of brushing on leaf colour in further pansy experiments. An increase in the SPAD reading indicates that the leaves are darker green in colour.

Dosage			**Time interval**			**Time of day**			**Times per week**		
Treatment	SPAD†		Treatment	SPAD		Treatment	SPAD		Treatment	SPAD	
	Experiment			Experiment			Experiment			Experiment	
	1	2		1	2		1	2		1	2
0	26	34	untreated	26	34	untreated	32	36	untreated	26	34
5	26	35	continuous	28	37	morning only	32	36	alternate days	26	35
10	27	36	1 minute intervals	28	36	afternoon only	32	35	5 days per week	26	36
20	26	38	10 minute intervals	28	36	morning & afternoon	33	38	every day	27	36
30	26	38									
40	27	36									
F tests			**F tests**			**F tests**			**F tests**		
overall	NS	NS	overall	NS	***	overall	NS	NS	overall	NS	*
brushed v. untreated	NS	NS	brushed v. untreated	**	***	brushed v. untreated	NS	NS	brushed v. untreated	NS	*
linear trend	NS	NS	continuous v. non-continuous	NS	NS	morning v. afternoon	NS	NS	linear trend	NS	*
			1 v. 10 minute intervals	NS	NS	1 v. 2 treatments per day	NS	NS			
$LSD_{0.05}$ (18 df)	-	-	$LSD_{0.05}$ (15 df)	-	1.1	$LSD_{0.05}$ (15 df)	-	-	$LSD_{0.05}$ (15 df)	-	1.6
SE of mean	0.8	0.8		0.6	0.5		0.7	0.7		0.6	0.6

NS, ***, **, * Main effects within column not significant at P = 0.05 or significant at P < 0.001, 0.01 or 0.05, respectively.

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for research/development project

Contract No: PC 85a
Contract Date: 21.11.95

1. TITLE OF PROJECT

BEDDING PLANTS: GROWTH REGULATION BY MECHANICAL BRUSHING

2. BACKGROUND AND COMMERCIAL OBJECTIVE

Mechanically induced stress is a potentially attractive means of keeping bedding plants compact whilst reducing the need for chemical plant growth regulators. Extensive reviews of the topic have been written by N. Biddington (HRI Wellesbourne) and J.G. Latimer (University of Georgia, USA) and there seems little doubt that most species of plants attain a compact habit when subjected to periodic and regular flexing which can be achieved by mechanical brushing (or stroking), shaking or by the use of blown air.

The use of blown air was investigated in HDC-funded trials on bedding plants at Littlehampton (HDC PC85). However, it rapidly became clear that the velocities of air required to achieve plant flexing (and, hence, stem shortening) for all except edge plants were extremely high, and would be too difficult to achieve with any semblance of uniformity on a commercial scale. Moreover, plants of sensitive species situated nearest the blowing nozzles shown symptoms of wind damage. Mechanical brushing would appear to be a more readily adaptable procedure for use in commercial cropping, since all plants can be readily treated and there is no significant leaf damage. This technique is already being introduced in the USA on vegetable transplants, particularly tomato, and there seems every reason to believe that the technology could be adapted for use with bedding plants.

An extremely able, Masters student at Cornell University, Lauren Garner, has developed manual brushing procedures for use by a US grower, Dan Riner of Triple "P" Greenhouses, who grows 2.5 million tomato transplants each year. The grower is extremely satisfied with the results obtained and is expanding the area to be treated this coming season and is now looking at ways of mechanising the treatments. Lauren Garner has expressed an interest in working at HRI Wellesbourne for 12 months to adapt her methods for use with bedding plants. A local grower (Findons) has agreed to provide plant material for trials at HRI Wellesbourne and to have proving trials done on his nursery and HRI is prepared to absorb the research costs. However, some further funding is required to top up the living expenses required and to enable her stay to be extended to 12 months so that trials can be done through the whole bedding plant season, including the difficult summer period.

The objective is to determine the feasibility of mechanical brushing for the commercial production of compact, high quality bedding plants.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

Potential benefits will be in improved control over plant stature, vital for the production of high quality plants, and in a reduction in the use of chemical plant growth regulators.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

The aim will be to determine whether mechanical brushing is effective in reducing the height of representative bedding plant species on which growth control is normally practised. The effects of duration, time of day and frequency of treatment will be tested for contrasting times of year. Follow-up trials will be done on a commercial bedding plant nursery to determine the potential of mechanical brushing for general adoption by bedding plant growers.

5. CLOSELY RELATED WORK

This work is an extension of PC85, Growth regulation by "air brushing". Other approaches to growth regulation have been and are being investigated. These include manipulation of growth by temperature (HDC- and MAFF- funding), but it has been judged that the level of environmental control required is beyond the means of most bedding plant growers. Control of irrigation and nutrition to control height is giving encouraging results with bedding plants in trials at HRI Efford (PC86).

6. DESCRIPTION OF THE WORK

Greenhouse trials will be carried out at HRI Wellesbourne (at HRI cost) over a three month period during Autumn/Winter 1995/6 to determine the relative sensitivities of a range of bedding plant species to mechanical brushing. Treatment will be given "by hand" and will cover both the seedling plug stage and the growing on stage after transplantation (with material supplied by Findons). Particular emphasis will be given to Impatiens, Petunia, Pansy and Geranium, the most widely grown bedding plant species. Additional observations will be made on other species as opportunities arise. It is expected that treatment variables will include duration of treatment, frequency of treatment and time of day effects. The precise details will be determined in consultation with Lauren Garner since she has the expertise on mechanical brushing.

Starting in Spring 1996, trials will move on to commercial crops at Findons Nursery, Stratford upon Avon. Experience gained in the small scale trials at HRI together with Lauren Garner's experience with the treatment of tomato transplants on a large scale in the USA, will be combined to determine the feasibility of mechanical brushing for use in commercial bedding plant production.

7. COMMENCEMENT DATE AND DURATION

01.12.95; duration 1 year

The visiting researcher will arrive in the UK in mid November and will work on the project for 12 months. The final report will be produced by the end of November

1996.

8. STAFF RESPONSIBILITIES

Project leader	Dr. F.A. Langton, HRI Wellesbourne
Researcher	Lauren Garner (ex Cornell University, USA)
Project Co-ordinator	Mr. Peter Byrne (Findons Nursery, Stratford upon Avon)

9. LOCATION

HRI Wellesbourne and Findons Nursery, Stratford upon Avon

Contract No: PC85a

TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature ....

Position ....C. M. Manager HRI......

Date ....4/1/96....

Signed for the Contractor(s)

Signature ....

Position ....

Date ....

Signed for the Council

Signature ....

Position ....CHIEF EXECUTIVE....

Date ....7.12.94....