Table 2. *Irrigation and drainage measurements from peat-grown tomatoes irrigated with fixed and variable nutrient solution concentrations at fixed and variable substrate water potential setpoints..*

Treatments		Irrigation data[z]					
		Irrigation			Drainage		
SMP (kPa)	EC ($dS\cdot m^{-1}$)	Liters/ plant	EC ($dS\cdot m^{-1}$)	pH	Liters/ bag	EC ($dS\cdot m^{-1}$)	pH
–5.0	2.5	1.12	2.22	5.69	1.44	3.21	5.93
–5.0	Variable	1.14	2.84**	5.76	3.06	3.40	5.76
Variable	2.5	1.27	2.30	5.78	2.13	2.69	5.90
Variable	Variable	1.21	2.75**	5.74	2.27	3.46	5.77
	LSD	NS	0.50**	NS	NS	NS	NS

[z]*Measurements were taken daily from each treatment. Variable treatments were as follows: –3.0 ≥ SMP ≥ –7.0 kPa and/or 1 ≥ EC ≥ 4 $dS\cdot m^{-1}$, according to calculated setpoints.*
***Significant at* P ≥ *0.01.*

able for irrigation management, especially those varying nutrient solution EC according to seasonal changes in crop water and nutrient demand. Results from preliminary experiments indicate that tensiometer–PET technologies can improve irrigation management in tomatoes growing in peat-based substrates. Irrigation regimes can therefore be changed automatically for different days or seasons to reflect changing environmental conditions influencing plant growth and development. The flexibility of this system enables it to be used under wide-ranging greenhouse environmental conditions.

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Hot-water Treatment and Indole-3-butyric Acid Stimulates Rooting and Shoot Development of Tropical Ornamental Cuttings

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Summary. Frangipani (*Plumeria* hybrid 'Donald Angus') cuttings immersed in hot water (49C for 10 min) followed by 0.8% indole-3-butyric acid (IBA) basal treatment (hot water + IBA) had greater root length and weight compared to the nontreated control, hot water, or IBA treatment alone. Greater percentage of rooting and number of roots per cutting were observed for hot-water-treated + IBA-treated cuttings compared to the non-treated control and hot-water treatment alone. In a second study, *Dracaena fragrans* (L.) Ker-Gawl. 'Massangeana', *D. deremensis* Engl. 'Warneckii', *D. deremensis* Engl. 'Janet Craig', *D. marginata* Lam., and cape jasmine (*Gardenia jasminoides* Ellis) cuttings displayed results similar to those observed with *Plumeria* cuttings. In addition to enhancing rooting, hot water + IBA also stimulated

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the number of shoots per cutting on anthurium (*Anthurium andraeanum* Andre 'Marian Seefurth'), croton [*Codiaeum variegatum* (L.) Blume var. *pictum* (Lodd.) Mull. Arg.], *D. marginata, D. fragrans, Plumeria,* and ti (*Cordyline terminalis* 'Ti') cuttings.

Hot-water immersion is an efficacious treatment against fruit flies and diseases (Couey, 1989; Klein and Lurie, 1992), plant-parasitic nematodes in various propagative materials (Higaki et al., 1979 ; Taylor, 1971); armored scales (*Pseudaulacaspis cockerelli* Cooley) on bird of paradise (*Strelitzia reginae* Aiton) leaves (Hara et al., 1993); soft scales (*Coccus viridis* Green) on cape jasmine(*Gardenia jasminoides* Ellis) cuttings (Hara et al., in press); and banana aphids (*Pentalonia nigronervosa* Coquerel), cotton aphids (*Aphis gossypii* Glover), earwigs (*Chelisoches morio* F.), ants (*Technomyrmex albipes* F. Smith), citrus mealybugs (*Planococcus citri* Risso), obscure mealybugs (*Pseudococcus affinis* Maskell), and longtailed mealybugs (*P. longispinus* Targioni-Tozzertti) on red ginger [*Alpinia purpurata* (Vieill.) K. Schum.] Hara et al., unpublished data). Hara et al. (in press) also reported that hot-water-treated cape jasmine cuttings exhibited greater shoot development, and speculated on the use of hot-water treatment to aid in the rooting of cuttings, especially when used in combination with indole-3-butyric acid (IBA).

Imported cuttings can be a source of serious pest introductions. Spencer (1981) concluded that the agromyzid leafminer [*Liriomyza trifolii* (Burgess)], originally a major pest of chrysanthemums in Florida, was introduced in 1977 into numerous nurseries in England, France, and the Netherlands through infested chrysanthemum cuttings from Kenya. Disinfesting propagative material with insecticidal dips such as fluvalinate is an option (Osborne, 1986). However, insecticidal dips expose workers to insecticides and pose potential hazards to consumers and the environment. A single, nonchemical postharvest treatment that not only will disinfest cuttings but also stimulate rooting would greatly assist the nursery industry in providing pest-free and highly viable cuttings. We report the effects of hot-water immersion on rooting nine tropical ornamental cuttings when applied at a time and temperature regime for insect disinfestation.

Study 1. *Plumeria* tip cuttings (15.2 cm) were harvested from the Univ. of Hawaii at Manoa, Waiakea Experiment Station in Hilo, and held in tap water at room temperature for a maximum of 1 h before treatment. Treatments included hot water, hot water followed by a basal application of 0.8% IBA rooting powder (Hormex, Brooker Chemical Corp., N. Hollywood, Calif.), 0.8% IBA application alone, and a nontreated control. Hot-water treatment consisted of immersing cuttings in water at 49C (120F) for 10 min. This temperature and duration was selected based on a report by Hara et al. (1993). Constant temperature was maintained and monitored using two isotemp immersion circulators (Model 730, Fisher Scientific, Pittsburgh) in a 106-liter stainless-steel tank. Water temperature was confirmed periodically using a digital and certified mercury thermometer. Water temperatures were maintained within ±0.1C of 49C throughout the 10-min treatment.

Immediately after hot-water treatment, cuttings were cooled in a water bath at ambient temperature (26.5C) for 5 min. Non-heated cuttings were immersed in a water bath at ambient temperature (26.5C) for 15 min. The base of each cutting was trimmed (0.6 cm), IBA was applied to the basal end of the appropriate treatments, and the cuttings were inserted ≈3.8 cm deep in 10.2-cm plastic pots containing vermiculite. Pots were arranged in a completely randomized experimental design on a greenhouse bench. Ninety-seven days after treatment, percentage of cuttings with roots and vegetative shoots, number of roots and vegetative shoots, and mean length of the three longest roots were determined. Dry weights of roots were determined after drying at 46C for 12 h. Percentages were transformed to arcsin square roots before analysis. Each treatment was replicated three times using 10 cuttings per replicate. Data were subjected to analysis of variance and means separated by Waller–Duncan k-ratio *t* test.

Study 2. Stem cuttings from nine ornamental species were treated with hot water followed by IBA basal treatment or IBA alone. The type of cuttings used are summarized in Table 1. Before treatment, all leaves were removed from the cuttings, except from croton and cape jasmine. Heat treatment, inserting procedures, and data collection were identical to those in study 1. The lengths of vegetative buds also were recorded. The average daily maximum and minimum temperatures were 36.4 ± 3.4C and 21.9 ± 0.9C, respectively, and the average daily maximum and minimum relative humidities were 95.7% ± 2.1% and 52.9% ± 11.2%, respectively. Data were analyzed by *t* test and the standard error of the mean was calculated.

Study 1. *Plumeria* cuttings immersed in hot water + IBA or treated with IBA alone had a significantly higher rooting percentage and more roots compared with hot water alone and control treatments (Table 2). Hot-water + IBA-treated *Plumeria* cuttings had significantly longer roots and greater root dry weight than cuttings treated with hot water or IBA alone. The percentage of cuttings with shoots and the number of shoots per cutting were not significantly different among treatments.

Study 2. Hot-water + IBA-treated cuttings had a higher rooting

Table 1. *Types and lengths of cuttings.*

Species / cultivar	n[z]	Type of cutting	Length (cm)	Days[y]
Anthurium andraeanum	25	Hardwood	≈15.2	29
Codiaeum variegatum	25	Tip	15.2	34
Dracaena deremensis 'Warneckii'	20	Hardwood	12.7	41
D. deremensis 'Janet Craig'	20	Hardwood	12.7	111
D. fragans	25	Hardwood	12.7	61
D. marginata	25	Hardwood	12.7	64
Gardenia jasminoides	25	Tip	15.2	27
Plumeria	25	Tip	15.2	48
Cordyline terminalis	25	Hardwood	15.2	29

[z]*Number of cuttings per treatment.*
[y]*Days to evaluation.*

Table 2. *Percentage of frangipani cuttings with roots and number, length, and dry weight of roots after hot-water treatment with and without 0.8% IBA.*

Treatment	Rooting (%)[z]	Roots No.	Roots Length (cm)	Roots Dry wt (g)[y]
Hot water + 0.8% IBA	76.7 a*	9.7 a*	4.5 a*	0.09 a**
Hot water	40.0 b	2.0 b	1.2 bc	0.02 b
0.8% IBA	53.3 ab	6.2 ab	2.4 b	0.04 b
Control	33.3 b	1.5 b	1.0 c	0.03 b

[z]*Percentage of cuttings with roots.*
[y]*Dry weight of root mass.*
Means within a column followed by different letters are significantly different by Waller–Duncan k ratio t *test, K = 100.*

percentage than cuttings treated with IBA alone for all plant species except *C. variegatum* and *C. terminalis* (Table 3). Numbers, lengths, and dry weights of roots were significantly greater for *G. jasminoides* and *D. fragrans*. Number and dry weight of roots were also significantly higher for treated *Plumeria* cuttings. Number of roots were significantly increased on *D. deremensis* 'Janet Craig'; however, root development (length, number, and dry weight of roots) on *C. variegatum* was inhibited by hot-water + IBA-treatment. There was no significant increase in root development after hot-water + IBA-treatment on *D. deremensis* 'Warneckii', *D. marginata*, and *C. terminalis* (Table 3).

The percentage of cuttings exhibiting vegetative growth was increased by hot-water + IBA-treatment with all tested species except *A. andraeanum*, *D. deremensis* 'Janet Craig', and *C. terminalis*, all of which exhibited 100% shoot development in both treatments (Table 4). Young leaves of *G. jasminoides* were injured by the hot-water treatment, but subsequent shoot development was increased significantly. The number of shoots per cutting that developed after the hot-water + IBA-treatment was increased significantly for all other species and varieties except for *D. deremensis* 'Warneckii', and 'Janet Craig'. The length of vegetative shoots was significantly higher on *Plumeria* only (Table 4).

Hot water is a new and effective tool for the pest-disinfestation of propagative cuttings (Hara et al., in press). Additional benefits of hot water + IBA include root and shoot stimulation for certain plant species. Hot-water + IBA-treated cuttings generally exhibited increased vegetative shoot development over those treated with IBA alone. Similar observations on breaking bud dormancy with hot water was reported for fruit trees, ornamental trees, corms, and seeds (Hartmann and Kester, 1983; Hosoki, 1984; Leopold, 1964). Although bud initiation before root development is often undesirable because of possible desiccation of the plant material (Hartmann and Kester, 1983), in our study hot-water + IBA-treated cuttings that displayed shoot development prior to rooting were rooted successfully without desiccation. The hot-water + IBA-treatment, which significantly stimulated axillary bud development on anthurium, will enhance subsequent anthurium propagation because each axillary shoot that develops on the cutting can be used to propagate a new plant (Higaki et al., 1979). Hot-water immersion also could be used as a single nonchemical treatment to disinfest cuttings of quarantine pests and enhance rooting of cuttings prior to export. For example, *P. cockerelli* is a serious pest of more than 50 species of ornamental plants in Florida and Georgia and accounts for most shipment rejections due to scale infestations of flower and foliage products exported from Hawaii (Hara et al. 1993; Reinert, 1974). However, exposure of adults, nymphs, and crawlers of *P. cockerelli* to water at 49C for 5, 5, and 6 min, respectively (5, 5, and 4 min less than our treatment time) resulted in 100% mortality (Hara et al., 1993). Hara et al. (in press) also demonstratedthat immersion (water at 49C for 10 min) of *G. jasminoides* cuttings infested with green scale (*Coccus viridis* Green) was 99.9% effective against adults and crawlers and 99.7% effective against nymphs, with no detrimental effects to the cuttings. At final destination, the hot-water-treated cuttings could be treated with IBA before planting to further enhance rooting.

To maximize the potential use of hot water in the nursery industry, additional research is being conducted to determine the optimum time and temperature regime for rooting individual plant species. Further tests also should

Table 3. *Percentage of cuttings with roots and mean number, length, and dry weight of roots after treatment in water at 49C for 10 min + 0.8% IBA or IBA alone.*

Commodity	Percent rooting: Hor water + IBA	Percent rooting: IBA alone	Roots[z] No./cutting: Hot water + IBA	No./cutting: IBA alone	Length (cm): Hot water + IBA	Length (cm): IBA alone	Dry wt (g)[y]: Hot water + IBA	Dry wt (g)[y]: IBA alone
C. variegatum	88.0	96.0	18.2 ± 2.5**	31.5 ± 2.2	3.3 ± 0.4*	4.6 ± 0.3	0.04 ± 0.01**	0.09 ± 0.01
D. deremensis								
'Warneckii'	90.0	75.0	4.6 ± 0.7	3.6 ± 0.7	4.7 ± 0.5	3.3 ± 0.7	0.04 ± 0.01	0.02 ± 0.01
'Janet Craig'	80.0	50.0	2.2 ± 0.4*	1.1 ± 0.3	4.2 ± 0.8	3.5 ± 1.0	0.04 ± 0.01	0.03 ± 0.01
D. fragrans	96.0	60.0	8.3 ± 0.9**	3.3 ± 0.8	7.5 ± 0.7**	3.1 ± 0.8	0.15 ± 0.02**	0.04 ± 0.01
D. marginata	80.0	56.0	7.6 ± 1.4	4.5 ± 1.3	2.9 ± 0.4	2.1 ± 0.5	0.05 ± 0.01	0.04 ± 0.01
G. jasminoides	84.0	44.0	118.3 ± 25.0**	15.6 ± 9.7	1.5 ± 0.3**	0.4 ± 0.2	0.06 ± 0.01**	0.01 ± 0.01
Plumeria	68.0	48.0	12.4 ± 3.3*	3.2 ± 0.9	2.5 ± 0.5	1.4 ± 0.4	0.07 ± 0.02*	0.02 ± 0.01
C. terminalis	88.0	92.0	11.2 ± 1.3	10.8 ± 1.4	2.4 ± 0.3	2.1 ± 0.3	0.05 ± 0.01	0.04 ± 0.01

[z]*Mean followed by ± SE.*
[y]*Dry weight of root mass.*
*,***Significant within row by* t *test,* $P \leq 0.05$ *or 0.01, respectively.*

Table 4. *Percentage of cuttings with vegetative shoot development, and mean number and length of shoots after treatment in water at 49C for 10 mion + 0.8% IBA or IBA alone.*

	Shoot[z]					
	Cuttings with shoot development (%)		No./cutting		Length (cm)	
Commodity	Hot water + IBA	IBA alone	Hot water + IBA	IBA alone	Hot water + IBA	IBA alone
A. andraeanum	100.0	100.0	5.7 ± 0.4**	3.9 ± 0.3	2.7 ± 0.2*	3.2 ± 0.2
C. variegatum	68.0	44.0	1.0 ± 0.2*	0.4 ± 0.1	---[y]	---
D. deremensis						
'Warneckii'	75.0	70.0	1.3 ± 0.2	1.3 ± 0.2	0.9 ± 0.2	0.7 ± 0.2
'Janet Craig'	100.0	100.0	2.9 ± 0.1	2.7 ± 0.1	---	---
D. fragrans	96.0	60.0	1.4 ± 0.1*	1.0 ± 0.2	0.6 ± 0.1	0.4 ± 0.1
D. marginata	88.0	68.0	2.1 ± 0.2*	1.4 ± 0.3	0.6 ± 0.1	0.8 ± 0.2
G. jasminoides	72.0	36.0	---	---	---	---
Plumeria	100.0	76.0	3.3 ± 0.2**	1.1 ± 0.2	8.6 ± 0.2**	5.6 ± 0.7
C. terminalis	100.0	100.0	4.6 ± 0.4**	3.4 ± 0.2	3.8 ± 0.3	3.4 ± 0.2

[z]*Mean* ± SE.
[y]*Data not taken.*
[*,**]*Significant within row by* t *test,* P ≤ *0.05 or 0.01, respectively.*

be conducted with hot water and other root-stimulating methods, including misting or fogging, application of bottom heat, or selection of optimum growth regulators and concentrations (Hartmann and Kester, 1983; Wang, 1988). The commercial use of hot-water immersion + IBA to disinfest and stimulate rooting and budbreak in cuttings is very promising because it is practical and affordable for high-volume propagation.

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