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A TEST OF FOUR HERBICIDES FOR USE ON STRAWBERRY GUAVA (*Psidium cattleianum* Sabine) IN KĪPAHULU VALLEY, HALEAKALĀ NATIONAL PARK

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A Test of Four Herbicides for Use on Strawberry Guava (*Psidium cattleianum* Sabine) in Kīpahulu Valley, Haleakalā National Park, Maui

Linda W. Pratt, Gregory L. Santos, and Charles P. Stone

ABSTRACT

Strawberry guava or waiawī (*Psidium cattleianum* Sabine), a tree native to Brazil, was intentionally introduced to the Hawaiian Islands in the early nineteenth century. It is now naturalized at low to middle elevations on all the main Hawaiian Islands except Ni'ihau and Kaho'olawe. A fast-growing species capable of spreading by seed or vegetative suckers, strawberry guava forms dense stands, which shade out native species and prevent their reproduction. Strawberry guava is the most serious invasive alien plant in the wet koa/'ōhi'a (*Acacia koa/ Metrosideros polymorpha*) forests of Kīpahulu Valley, Haleakalā National Park, Maui.

In 1987-88 ten herbicide treatments were tested on strawberry guava trees at two mid-elevation wet forest sites in Kīpahulu Valley. Six treatments involved application of Garlon 3A (triclopyr, triethylamine salt) or Garlon 4 (triclopyr, butoxyethyl ester) to cut stumps of guava (undiluted, 50%, and 5% dilutions in either water or citrus oil). Control treatments were cut stumps sprayed with either water or citrus oil. One treatment was undiluted Garlon 3A applied to continuous frill cuts on guava trunks, and another was 50% Garlon 4 in citrus oil applied as a thinline to the basal bark of large trees. Additionally, at one of the wet forest sites, two soil application methods (spot or broadcast) were tested with two different herbicides: Spike 20P (tebuthiuron) or Velpar (hexazinone). Systematically selected untreated trees served as a control for the four soil treatments.

The most effective treatment for strawberry guava tested in Kīpahulu Valley was undiluted Garlon 4 applied to cut stumps; 21 months after herbicide application, this treatment had killed 80% of guava trees. Trees 5 cm or larger in diameter were more likely to survive treatment. The undiluted Garlon 4 treatment had the lowest number of resprouting stumps and the fewest resprouts per stump. All cut-stump treatments were better at inhibiting resprouts than were the water or citrus oil controls. Garlon 3A, 5% dilution in water, was significantly less effective than other treatments. The application of 50% Garlon 3A to continuous frill cuts on guava trunks was also moderately effective, resulting in the death of 55% of strawberry guava after 21 months. The thinline application of 50% Garlon 4 in citrus oil to the basal bark of guava was ineffective; no trees were killed by this treatment. Garlon 3A and Garlon 4 applied to cut stumps, frill cuts, or the basal bark of guava trees did not adversely

affect native plants in plots surrounding treated strawberry guava. No significant losses of 14 native plant species were observed during 21 months of monitoring.

Soil treatments with Velpar and Spike 20P were not effective in controlling strawberry guava. Native plants surrounding guavas in treated plots were adversely affected in Spike treatment plots.

The recommended treatment for strawberry guava in Kīpahulu Valley is the cut-stump application of undiluted Garlon 4. Because of potential re-rooting of cut slash and the less than 100% kill achieved with Garlon 4, further research with other application techniques and herbicides is suggested.

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INTRODUCTION

Strawberry guava or waiawī (*Psidium cattleianum* Sabine) was a relatively early introduction to Hawai'i, arriving in 1825 (Nagata 1985). Native to Brazil, the tree is widely naturalized and today occurs on all the Hawaiian Islands except Ni'ihau and Kaho'olawe. Varying from a large shrub to a medium-statured tree, strawberry guava has smooth, peeling bark and glossy dark green leaves with a leathery texture and inconspicuous veins. Borne in leaf axils, flowers are small with numerous prominent stamens and white petals about 5 mm (0.2 in.) long. The edible fruit, for which the plant was probably introduced, is a round, fleshy berry 2 to 3 cm (0.8-1.2 in.) in diameter and may be either red or yellow in color (Wagner *et al.* 1990).

Strawberry guava is one of the most serious threats to Hawai'i's rain forests because of its ability to form dense monotypic stands, which shade out native understory species and prevent native plant reproduction (Smith 1985). The species is a prolific producer of fruit, and seeds have a high germination rate; in addition, it can rapidly increase cover through the production of fast-growing suckers (Huenneke and Vitousek 1990). A species with wide ecological tolerances, strawberry guava has been found to an elevation of 1,300 m (4,260 ft) in 23 different vegetation types on the island of Hawai'i (Jacobi and Warshauer 1992).

In Kīpahulu Valley, Maui, strawberry guava is recognized as the worst alien plant threat to the middle-elevation koa (*Acacia koa*) forests of Haleakalā National Park (Loope *et al.* 1992). While the date of strawberry guava establishment in Kīpahulu Valley is not known, the tree has expanded its range upslope in the last two decades. During a scientific expedition in 1967, strawberry guava was observed only to 670 m (2,200 ft) elevation in Kīpahulu Valley (Lamoureux 1968). Nine years later, the tree had become much more common between 610 and 915 m (2,000-3,000 ft) elevation (Lamoureux and Stemmermann 1976). By 1980, the species was reported at elevations of 760 m (2,500 ft) in the lower plateau and 1,140 m (3,750 ft) in the upper plateau, with dense stands noted below 850 m (2,800 ft) (Yoshinaga 1980).

In 1985, as part of a major effort to exclude and remove feral pigs (*Sus scrofa*) from the more intact, upper reaches of Kīpahulu, a fence was built across the valley at an elevation of 945 m (3,100 ft) in the upper plateau and at 700 to 730 m (2,300-2,400 ft) in the lower valley. Removal of pigs, the major disturbance factor in the part of Kīpahulu Valley above the fences, permitted managers to emphasize alien plant control. This study was carried out to test four herbicide formulations against strawberry guava in the area where alien plant control would be initiated.

THE STUDY AREA

One of the largest valleys on windward East Maui, Kīpahulu Valley became part of Haleakalā National Park in 1969. The valley is composed of two plateaus (upper and lower valleys) separated by a cental pali or cliff (Fig. 1). This two-level topography is the result of late eruptive volcanic activity in the ancient eroded valley, followed by stream erosion and even more recent flows (MacDonald and Abbott 1979). The lower (eastern) valley contains the most recent substrates (Diong 1982). Soils in Kīpahulu Valley are classified as Hydrandepts or Tropaquods, which are soils high in organic matter over either ash, cinders, or ironstone. They vary from well- to poorly-drained (Foote *et al.* 1972). Kīpahulu rain forest soils are very acidic, highly leached, and generally shallow (Diong 1982).

The climate of windward East Maui is typically very wet. In Kīpahulu Valley, mean annual rainfall varies with elevation, ranging from 2,000 mm (79 in.) near the coast to greater than 5,000 mm (197 in.) at the sites of herbicide tests near 945 m (3,100 ft) elevation (Giambelluca *et al.* 1986). Mean monthly rainfall is less in summer months than in the winter, but no actual dry season occurs regularly in Kīpahulu (Diong 1982). Long-term temperature data are not available for Kīpahulu Valley, but DeWreede (1968) recorded temperatures at 945 m (3,100 ft) ranging from 16.8 to 22.5^{o} C (62-72.5^{o} F) over a period of 10 days in the summer of 1967.

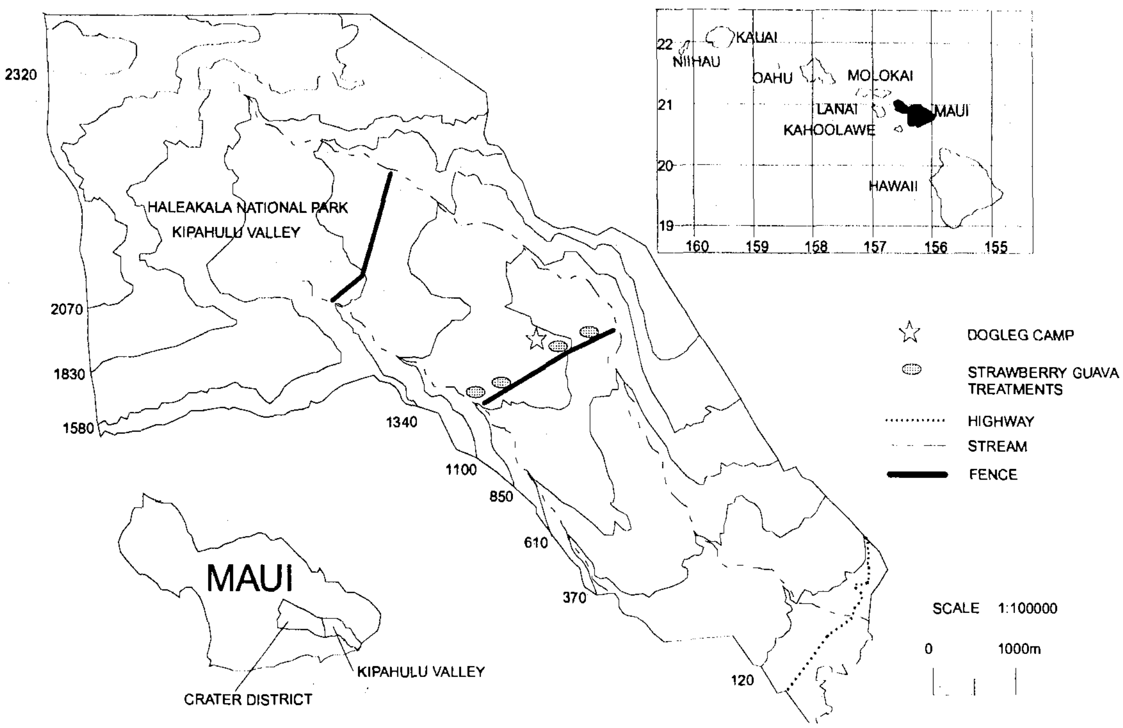

Figure 1. Sites of strawberry guava (*Psidium cattleianum*) treatments in Kīpahulu Valley, Haleakalā National Park (contours in m.).

The specific sites in Kīpahulu Valley selected for the strawberry guava herbicide tests were directly above fences constructed to exclude feral pigs and goats (*Capra hircus*) at 945 m (3,100 ft) and 975 m (3,200 ft) elevation in the upper valley and 730 m (2,400 ft) in the lower valley (Fig. 1). In the upper valley, guava trees selected for cut-stump treatments were along a trail following the edge of the Koukouai Stream gulch on the extreme western side of Kīpahulu. Trees selected for the soil application test were near the "Dogleg" camp on the eastern side of the upper valley near the edge of the central pali. In the lower (eastern) valley, strawberry guava trees used in cut-stump and frill tests were in a grove adjacent to the fence or along a trail that followed a low ridge upslope from the fence.

Vegetation at the upper sites was mapped by Smathers (1968) as koa/ hapu‘u (*Cibotium* spp.) forest with ‘ie‘ie *(Freycinetia arborea)*, scattered ‘ōhi‘a (*Metrosideros polymorpha*), and ‘ōlapa (*Cheirodendron trigynum*). The lower site was classified as an open koa/‘ōhi‘a/‘olapa forest with ‘ie‘ie. Jacobi (1980, 1983) mapped the vegetation of both upper and lower sites as wet koa/‘ōhi‘a forest with a predominently alien understory.

METHODS

Four herbicides were tested against strawberry guava: two formulations of triclopyr,* hexazinone, and tebuthiuron. The commercial formulations used were Garlon 3A** (0.36 kg acid equivalent [ae]/liter as the triethylamine salt of triclopyr); Garlon 4 (0.48 kg ae/liter as the butoxyethyl ester of triclopyr, Dow Chemical), Velpar (hexazinone, 90% active ingredient [ai] soluble powder, Du Pont); and Spike 20P (tebuthiuron 20% ai pellets, Elanco).

Fourteen treatments were used in this test. The two Garlon formulations were separately tested on freshly cut stumps undiluted and at 5 and 50% volume/volume dilutions in water or Cide-kick citrus oil (100% d'Limonene, JLB International Chemical). Water was the carrier for Garlon 3A, and citrus oil was the carrier for Garlon 4. Controls for the cut-stump treatments were one set of trees cut and sprayed with plain water, and a second set of cut stumps treated with citrus oil alone. Undiluted Garlon 3A was also applied to basal continuous frill cuts, and 50% Garlon 4 in citrus oil was tested as a thinline basal bark treatment.

Spike 20P and Velpar were tested as soil applications, Spike at 6.7 kg active ingredient (ai)/hectare (ha) and Velpar at 13.5 kg ai/ha. Two methods of soil application were used for both herbicides: the chemical was either evenly broadcast over the study plot, or concentrated in a single spot at the drip line of the target guava tree. Untreated trees were used as controls in the soil application tests. Soil treatments were applied in May 1988, when strawberry guava trees were beginning to put out new leaves (flush).

Tree Selection and Herbicide Application

Cut-Stump, Frill, and Basal Bark Treatments. Sample size for the cut-stump, frill, and thinline basal bark tests was twenty trees per treatment. In the cut-stump test both single and multiple-trunked trees were used with ten "small" (1-4 cm basal diamater of the largest stem) and ten "large" (5 cm or larger) trees selected for each treatment. In the frill and thinline basal bark tests, only single-trunked "large" trees were selected.

For the cut-stump treatments, trees of excellent or good vigor in the appropriate size categories were selected from two strawberry guava populations: one in the upper valley along a trail on the edge of the Koukouai gulch, and the second in the lower valley along a trail extending upslope from the cross-valley fence. Each tree of suitable size and vigor

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* Chemical names of herbicides used are **triclopyr** ([3,5,6-trichloro-2-pyridinyl] oxyacetic acid), **hexazinone** (3-cyclohexyl-6-[dimethyl-amino]-1-methyl-1,3,5-triazine-2,4[1H,3H]-dione), and **tebuthiuron** (N-[5-(1,1-dimethylethyl)-1,3,4-thiadizol-2-yl]-N,N'-dimethylurea).

** Reference to a company or product name does not imply endorsement by the National Park Service.

along these trails was used, with adjacent trees receiving the same treatment, and treatments separated by a distance of 5 m (16 ft). An attempt was made to select distinct individuals rather than suckers or clones in each treatment group. Trees selected to treat were at least 1 m apart and did not appear to be connected underground. At both upper and lower valley sites, each cut-stump treatment contained 10 trees, with an equal number of "small" and "large" trees. A treatment was randomly selected for each group of trees, and the trees were cut as close to the ground as possible with a chainsaw. The selected treatment was applied immediately to the entire surface of freshly cut stumps. This procedure was repeated for the remaining treatments until all were applied.

Trees selected for the frill and thinline basal bark treatments were all in the lower valley in a grove directly upslope of the fence. Treated trees were a minimum of 2 m (7 ft) apart. In the frill test, a hand ax was used to create a continuous overlapping frill around the base of the tree. The cuts were made at an oblique angle, forming a cup. The herbicide was applied immediately into this cut at a rate of approximately 1 ml/2.5 cm basal diameter. In the thinline basal bark test, the herbicide was applied as a thin continuous stream around the base of the trunk at the 1 ml/2.5 cm diameter rate.

Soil Treatments. Soil application of herbicides was tested only in the upper valley near the "Dogleg" camp on the edge of the central pali. Trees selected were along the central pali trail. All trees of suitable size and good vigor within 10 m of the trail were selected, starting at the fence line and working upslope. Nearby trees received the same treatment, and a minimum of 5 m (16 ft) separated different treatments. Sample size for the soil tests was 10 trees per treatment, five in the "small" diameter class and five in the "large" class, either single or multiple trunked. The size of the strawberry guava clump was measured from the trunk center to the drip line, and the amount of herbicide equaling the per acre rate was applied to the ground. In the broadcast treatments, the herbicide dose was evenly distributed over the entire test plot; in the spot treatments the entire herbicide dose was applied to a single spot along the drip line of the tree. The control was a group of untreated strawberry guava trees of good vigor and similar size along the trail 5 m away from the herbicide treatments.

Monitoring

The cut-stump, frill, and thinline basal bark treatments were applied in August 1987. Monitoring was done 5, 9, 14, and 21 months after treatment. Soil application tests were initiated in 1988, and plots were monitored 5 and 12 months post treatment. At each treated strawberry guava, the number of resprouts was estimated, stratified as "low" (1-10), "medium" (11-50), or "high" (>50). Cambium color (green, yellow, or brown) and resprout vigor (excellent, good, fair, poor, or dead) were also evaluated at each tree or stump. Several cuts were made to examine the cambium layer at different spots near the base of each stump. Resprouts of excellent vigor were exceptionally vigorous and had dark green, turgid leaves with glossy cuticle and no chlorosis. Those evaluated as good had glossy, turgid leaves with no deformities and less than 10% chlorosis. Resprouts with fair vigor had light green leaves with dull cuticles, some flaccidity, stunting, or abnormalities. Chlorosis was present on 10-50% of leaves, and some necrosis was noted. Poor guava resprouts had deformed, stunted, and severely chlorotic leaves with flaccidity and necrosis pronounced. Dead shoots had leaves and stems fully necrotic. In the frill, thinline basal bark, and soil tests, canopy vigor and the amount of leaf loss were estimated. In the cut-stump tests, any production of roots or shoots on the cut slash was recorded.

Native plants. Before treatments were applied, native plants within a 1 m radius of each strawberry guava were counted in size classes (<0.1 m, 0.1-0.5 m, >0.5-1 m, >1-2 m, >2-3 m, >3-5 m, >5-10 m, and >10 m). Native plant vigor was assessed as excellent (exceptionally vigorous), good (healthy and normal for the species), fair (showing some discoloration, wilting, or damage), poor (exhibiting heavy loss of chorophyll, wilting, drying, or leaf loss), or dead. Native plants were recounted and reevaluated at intervals of 5, 9, 14, and 21 months. In the soil application plots, native plants were monitored 5 and 12 months after treatments.

Data Analysis

In the cut-stump, frill, and basal bark treatments, data collected on the number of resprouts and their heights after 21 months were analyzed using the microcomputer version (6.03) of the Statistical Analysis System (SAS) (Statistical Analysis System 1985). When the sample size was equal among treatments, the analysis of variance procedure was used, and the Waller Duncan K-ratio t test was used to separate treatment means. When the sample size for a variable was unequal among treatments (as with resprout heights), the general linear models procedure was specified for analysis of variance, and Tukey's studentized range test was used to evaluate mean separation.

Using a SAS frequency procedure that computed chi-square, cambium vigors (color) of strawberry guava at 21 months post treatment were analyzed by comparing the number of stumps with brown or green cambium in any treatment with the equivalent numbers in the water or citrus oil controls. If the herbicide was mixed with water, the cambium data were compared with the water control data; for the Garlon 4 treatments, the comparison was with the citrus oil control. Because yellow cambium often turned brown by the end of the study, the yellow and brown categories were combined and compared with the green category in the chi-square analysis. Chi-square values reported here were corrected for continuity (Snedecor and Cochran 1971).

In the soil treatments, differences in number and height of resprouts and cambium vigors were not statistically analyzed. Canopy vigor among soil treatments was evaluated by comparing the number of trees with greater than 50% defoliation at 12 months among treatments and the control and calculating a chi-square value.

In the cut-stump, frill, and basal bark treatments, data collected on native plants in the 1-m radius plots centered on each treated or control strawberry guava were analyzed with SAS. The change in number of individuals greater than 0.1 m in height over 21 months was analyzed for each native species found in each treatment plot. As the sample sizes of native plants were unequal in the different treatments, the general linear models procedure was used for the analysis of variance, and Tukey's studentized range test was used to separate the means among treatments. In the soil treatments, change in native plant numbers over 12 months was analyzed using the non-parametic Kruskal-Wallis chi-square approximation test.

RESULTS

Cut-stump, Frill, and Thinline Basal Bark Treatments

TREATMENT EFFICACY

Undiluted Garlon 4 applied to cut stumps was the most effective treatment of those tested on strawberry guava in Kīpahulu Valley. This treatment had the highest number of apparently dead guava trees with brown cambium, the lowest number of resprouting stumps, the lowest number of resprouts (among cut-stump treatments), and the second-lowest mean resprout height. A statistically significant difference in the number of resprouts was detected among the cut-stump, frill, and basal bark treatments ($F = 21.9$, $p < 0.0001$). All herbicide treatments were significantly better at inhibiting resprouting than were the water or citrus oil control treatments ($p = 0.05$) (Table 1), and 5% Garlon 3A was significantly less effective than the other herbicide treatments. A significant difference was also found in resprout height among treatments ($F = 19.6$, $p = 0.0001$). All herbicide treatments had significantly lower mean resprout heights than the water or citrus oil controls, but no significant difference among the six cut-stump herbicide treatments was detected.

Table 1. Mean number of resprouts in strawberry guava (*Psidium cattleianum*) cut-stump, frill, and basal bark treatment groups, compared with the Waller Duncan K-ratio t test.

Treatment	Mean No. Resprouts	Waller Duncan Group*
Citrus Oil	34.3	A
Water	23.8	B
5% Garlon 3A - cut	14.3	C
50% Garlon 4 - basal bark	3.3	D
Undiluted Garlon 3A - cut	3.0	D
5% Garlon 4 - cut	2.3	D
50% Garlon 3A - cut	1.8	D
50% Garlon 4 - cut	0.8	D
Undiluted Garlon 4 - cut	0.3	D
Undiluted Garlon 3A - frill	0	D

*Treatments with different letters are significantly different ($p = 0.05$).

Garlon 4 Cut-stump Treatments. The 5% dilution of Garlon 4 in citrus oil killed nine (45%) of the cut strawberry guava trees by 21 months post treatment; eight of these appeared dead at the 9-month monitoring (Table 2). One stump showed brown cambium and appeared dead at the 9 and 14-month monitorings, but had green cambium and a few (< 10) resprouts at the end of the study. Seven of the 11 surviving stumps were "large," $\geq$ 5 cm basal diameter. A total of nine stumps resprouted by the end of the study with 1 to 10 shoots. These resprouts were of excellent vigor and averaged 72.4 cm in height. Cambium death (indicated by brown color) was not significantly greater than in the citrus oil control (adjusted chi square = 2.98, p = 0.084).

The 50% dilution of Garlon 4 in citrus oil killed 10 guava (50%) within 21 months; one additional stump appeared dead at the 14-month monitoring but subsequently showed green cambium. About half (6) of the surviving stumps were "small," 1 to 4 cm in diameter. Only three of the 50% Garlon 4-treated stumps resprouted during the study with very few resprouts (1-10) of good vigor, averaging 30.7 cm in height. This dilution of Garlon 4 killed the cambium of significantly more guava than did citrus oil alone (adjusted chi square = 4.10, p = 0.043).

Undiluted Garlon 4 was the most successful cut-stump treatment, killing 16 strawberry guava (80%) by 21 months. Three of the four surviving stumps were "large" trees ($\geq$ 5 cm basal diameter) and were, in fact, the largest trees of the treatment. Three other stumps appeared dead 14 months after treatment, but green cambium was detected by the end of the study. Only one stump resprouted within 9 months of treatment; its few shoots were healthy, averaging 48.0 cm at 21 months. A highly significant difference was found in the number of Garlon 4-treated stumps with brown cambium, as compared with the water control stumps (adjusted chi square = 23.4, p < 0.0001).

Garlon 3A Cut-stump Treatments. The most dilute solution of Garlon 3A tested (5%) was ineffective in killing strawberry guava; only one stump was killed after 21 months. Most treated stumps (18) resprouted by the end of the study, with resprouts of excellent vigor averaging 63.5 cm in height (Table 2). Almost all stumps in this treatment retained green cambium throughout the study, and no significant difference was detected in the number of stumps with live cambium in the 5% Garlon 3A treatment and the water control (adjusted chi square = 0, p = 1.00). Two stumps had brown cambium at 14 months, but subsequently they resprouted and displayed green cambium at the 21-month monitoring.

The 50% Garlon 3A treatment killed nine strawberry guava (45%) by 14 months post treatment, with no improvement in kill at 21 months. Most of the surviving stumps (7) were "large" trees ($\geq$ 5 cm diameter). Seven stumps resprouted and bore 1 to 10 resprouts of good vigor with a mean height of 61.6 cm. The number of stumps with dead cambium differed significantly from that in the water control (adjusted chi square = 10.8, p = 0.001).

Table 2. Effects of cut-stump, frill, and basal bark herbicide treatments on strawberry guava (*Psidium cattleianum*) in Kīpahulu Valley, Haleakalā National Park, 1987-1988.

Treatment	Mean Basal Diameter (cm)	Time Since Treatment (mos)	No. Dead or Moribund* (n = 20)	No. Trees w/ Resprouts	Mean No. Resprouts**	Mean Resprout Height (cm)	No. with Brown/Yellow Cambium	No. with Rooting Slash (n = 20)
5% Garlon 3A/Water Cut Stump	6.1	5	1	2	0.5	11.0	2	2
		9	2	11	5.3	8.4	4	0
		14	3	14	13.0	51.3	4	0
		21	1	18	14.3	63.5	1	1
50% Garlon 3A/Water Cut Stump	5.6	5	6	2	0.5	5.5	10	1
		9	4	4	1.0	2.8	10	2
		14	9	6	1.5	19.5	10	2
		21	9	7	1.8	61.6	10	0
Undiluted Garlon 3A Cut Stump	8.0	5	4	1	0.3	2.0	8	0
		9	2	4	1.0	4.3	4	0
		14	9	4	2.3	20.0	10	0
		21	8	7	3.0	43.7	8	1
5% Garlon 4/Citrus Oil Cut Stump	5.5	5	2	1	0.3	10.0	5	2
		9	8	2	0.5	7.0	10	2
		14	10	6	1.5	40.0	10	3
		21	9	9	2.3	72.4	9	0
50% Garlon 4/Citrus Oil Cut Stump	6.5	5	11	0	0	N/A	13	0
		9	7	1	0.3	1	11	1
		14	11	2	0.5	15.0	12	3
		21	10	3	0.8	30.7	10	3

Table 2, continued.

Treatment	Mean Basal Diameter (cm)	Time Since Treatment (mos)	No. Dead or Moribund* (n = 20)	No. Trees w/ Resprouts	Mean No. Resprouts**	Mean Resprout Height (cm)	No. with Brown/Yellow Cambium	No. with Rooting Slash (n = 20)
Undiluted Garlon 4	4.6	5	16	0	0	N/A	17	1
Cut Stump		9	14	0	0	N/A	16	2
		14	19	1	0.3	30.0	19	2
		21	16	1	0.3	48.0	16	4
Citrus Oil Only	5.6	5	1	15	21.3	18.0	2	9
Cut Stump		9	1	18	31.3	44.2	1	0
		14	2	17	22.3	88.4	2	0
		21	3	17	34.3	119.8	3	2
Water	5.4	5	0	20	35.3	27.2	0	1
Cut Stump		9	0	20	37.8	66.9	0	1
		14	0	20	38.8	109.0	0	0
		21	0	20	23.8	155.0	0	1
Undiluted Garlon 3A	10.9	5	12	0	0	N/A	15	N/A
Frill		9	7	0	0	N/A	7	N/A
		14	13	0	0	N/A	13	N/A
		21	11	0	0	N/A	11	N/A
50% Garlon 4/Citrus Oil	11.7	5	0	0	0	N/A	0	N/A
Thinline Basal Bark		9	0	4	1.0	6.8	0	N/A
		14	0	7	15.1	49.1	0	N/A
		21	0	8	8.1	67.0	0	N/A

* Number of trees with brown cambium and no resprouts; appeared to be dead. For frill treatment, number of trees with brown cambium, no resprouts, and dead canopy with all leaves brown or fallen.

** Calculated from category mid-points (0, 1-10 = 5, 11-50 = 30, >50 = 51).

Treatment with undiluted Garlon 3A resulted in the death of eight guava (40%) by 21 months. Two-thirds of the survivors (8) were "large" trees. Seven treated stumps resprouted, and by the end of the study these had 1 to 10 vigorous resprouts with a mean height of 43.7 cm. A few stumps (4) had brown cambium at 14 months but were found to have green cambium at the 21-month monitoring; only one of these resprouted. In the undiluted Garlon 3A treatment, the number of stumps with brown cambium (at 21 months) was significantly greater than the number that died in the water control (adjusted chi square = 7.66, p = 0.006).

Water and Citrus Oil Controls. Strawberry guava trees cut and sprayed with water survived and remained alive with green cambium 21 months after treatments. All 20 trees resprouted within 5 months and bore 11 to 50 healthy new shoots. The citrus oil treatment (used as a control for Garlon 4 dilutions) killed three guava by the end of the study. The other 17 stumps treated with citrus oil resprouted within 9 months with 11 to 50 shoots. Resprouts were of excellent vigor and averaged 119.8 cm in height by the end of the study. No significant difference was detected in the number of dead stumps between the water and citrus oil controls (adjusted chi square = 1.4, p = 0.230).

Frill and Thinline Basal Bark Treatments. The frill application of undiluted Garlon 3A resulted in the apparent death of 11 strawberry guava (55%) 21 months after treatment; all of these displayed brown cambium at multiple points below the frill cuts. None of the trees resprouted leafy shoots, but all 20 developed adventitious roots along the trunk within 9 months of treatment. Canopy defoliation was greater than 75% on all trees at the 5-month monitoring, and the frilled trees did not show any increase in foliage throughout the study.

The thinline application of 50% Garlon 4 in citrus oil to the bark at the base of strawberry guava was ineffective; no guava trees were killed, and all displayed green cambium at the end of the study. Basal sprouting was observed on eight guava in the Garlon 4 thinline bark treatment. These trees supported 1 to 10 highly vigorous resprouts, which grew to an average height of 67.0 cm. Adventitious rooting also occurred on all basal bark-treated guava, at or near the site of herbicide application. The canopy was heavily defoliated (>75%) on three trees at 5 months, and by 21 months one of these trees had lost >99% of canopy leaves. The other trees in this treatment showed 10 to 100% defoliation at their tops, but the lower half of each canopy had no loss of leaves.

EFFECTS ON NATIVE PLANTS

More than 25 native plant species occurred in plots surrounding treated strawberry guava trees, and 17 were common enough to permit analysis of change over the monitoring period of 21 months.

Trees and Shrubs. The most abundant tree in the study area was koa; seedlings and saplings <1 m tall occurred in most study plots. Koa increased over 21 months in plots of all treatments except 5% Garlon 4; differences among treatments were not significant (Table 3). The co-dominant ‘ōhi‘a was also common in study plots, where increases in number were seen in all but the 50% Garlon 4 cut-stump treatment. This small variation among treatments was not significant.

Table 3. Results of an analysis of variance among ten treatments for change in number of individuals of 17 native plant species in strawberry guava (*Psidium cattleianum*) test plots in Kīpahulu Valley, Haleakala National Park.

Species (Common Name)	Life Form	No. Treatments Containing Species	N*	F*	p*
Acacia koa (koa)	tree	10	86	1.85	0.0735
Antidesma platyphyllum (hame)	tree	10	24	1.15	0.3922
Asplenium spp. (spleenwort)	fern	9	38	4.09	0.0023**
Athyrium microphyllum ('ākōlea)	fern	10	27	1.35	0.2848
Broussaisia arguta (pū'ahanui)	shrub	10	73	0.99	0.4577
Cheirodendron trigynum ('ōlapa)	tree	9	42	1.41	0.2295
Cibotium chamissoi (hāpu'u 'i'i)	fern	7	12	1.11	0.4638
Ctenitis spp. (pauoa)	fern	7	18	2.40	0.0988
Diplazium sandwichianum (pahole)	fern	10	111	0.59	0.8025
Hedyotis terminalis (manono)	tree	8	30	2.62	0.0394**
Melicope clusiifolia ('alani)	tree	8	39	2.73	0.0251**
Metrosideros polymorpha ('ōhi'a)	tree	8	38	0.10	0.9981
Peperomia spp. (ala ala wai nui)	herb	10	35	0.90	0.5387
Psychotria sp. (kōpiko)	tree	9	40	1.19	0.3380
Sadleria pallida ('ama'u)	fern	7	33	1.45	0.2331
Vaccinium calycinum ('ōhelo)	shrub	7	12	0.11	0.9902
Vandenboschia davallioides (kilau)	fern	8	27	1.24	0.3296

* N = sample size (number of plots). F = variance ratio. p = probability.
** Treatments significantly different at the 95% level of confidence.

Four other tree species frequently occurred in guava plots: 'ōlapa (*Cheirodendron trigynum*), kōpiko (*Psychotria* sp.), hame (*Antidesma platyphyllum*), and 'alani (*Melicope clusiifolia*). Small decreases in young 'ōlapa trees were noted in both undiluted Garlon treatments, 50% Garlon 4, and the basal bark application plots. In other treatments, the number of 'ōlapa remained the same. Kōpiko numbers declined slightly in plots of 50% Garlon 4, 50% Garlon 3A, and the undiluted Garlon 3A frill treatment, but other treatments showed small increases or no change. Hame numbers were static throughout the monitoring period except for the loss of two small saplings in undiluted Garlon 3A plots. 'Alani was the only tree species for which changes over 21 months differed significantly among treatments (F = 2.75, p = 0.025). Losses in 'alani saplings and small trees were relatively large in the 5% Garlon 3A treatment. Smaller losses were noted in the 5% and undiluted Garlon 4 plots. Plots of other treatments showed increases or stayed the same.

Only three native shrub species were widely distributed in the study area: pū'ahanui (*Broussaisia arguta*), 'ōhelo-kau-la'au (*Vaccinium calycinum*), and manono (*Hedyotis terminalis*). Pū'ahanui numbers decreased slightly in both the undiluted Garlon 3A and Garlon 4 treatments and in the citrus oil control. In other treatments, small increases were observed. 'Ōhelo numbers stayed the same in all treatments throughout the year. Only manono showed differences among treatments that were statistically significant (F = 2.62, p = 0.039). This viny shrub decreased in numbers in the 5% Garlon 3A and citrus oil treatments and increased in all others.

<u>**Ferns and Herbs**</u>. The ground cover of the study area was composed primarily of ferns, and the most abundant of these was pahole (*Diplazium sandwichianum*). This large terrestrial fern increased in all but the 5% Garlon 3A cut-stump and the undiluted Garlon 3A frill treatments, which had insignificant losses of one to three plants. Other common ferns, such as 'ākōlea (*Athyrium microphyllum*), hāpu'u 'i'i (*Cibotium chamissoi*), pauoa (*Ctenitis* sp.), and kilau (*Vandenboschia davallioides*), showed very small losses in one or more treatments or controls, and differences among treatments were not significant. 'Ama'u (*Sadleria pallida*) numbers increased or stayed the same in all treatments throughout the monitoring period. The only fern for which a significant loss was detected was spleenwort (*Asplenium* sp.) (F = 4.09, p = 0.002). Fourteen of 22 spleenworts growing in control plots disappeared over 21 months. A small loss also occurred in the 50% Garlon 4 plots, but all other treatment plots showed increases of this fern.

The only other common herbaceous plant in the study area was 'ala'ala wai nui (*Peperomia* spp.). Losses of these fragile-stemmed, succulent plants were observed in most treatments, but differences among treatments were not significant.

Soil Treatments

TREATMENT EFFICACY

All four herbicide treatments applied to the soil surrounding strawberry guava were completely ineffective in killing this alien tree. No guava trees in either Velpar or Spike treatments died during the monitoring period of 12 months, and all retained green cambium throughout the study. Twelve months after treatment, no significant difference was found in the canopy vigor among the four herbicide treatments and the untreated controls (chi square = 4.72, p > 0.25).

<u>**Velpar**</u>. After 5 months, defoliation was greater than 50% on four Velpar spot-treated trees (Table 4), and an additional four showed 10-50% defoliation. By 12 months post treatment, some recovery in foliage was noted and only two trees had >50% leaf loss. These two trees also bore several (1-10) unusual stem sprouts that may have been caused by the herbicide treatment. After 5 months, chlorosis along leaf veins was observed on seven trees in the Velpar plot treatment. Twelve months after treatment, five trees showed chlorosis on up to 10% of their leaves.

Table 4. Effects of soil-applied herbicides on strawberry guava (*Psidium cattleianum*) in Kīpahulu Valley, Haleakalā National Park, 1988.

Treatment	Mean Basal Diameter (cm)	Time Since Treatment (mos)	No. Dead or Moribund* (n = 10)	No. Trees w/ Resprouts	Mean No. Resprouts	No. with Brown/Yellow Cambium	No. with > 50% Defoliation	No. with 10-50% Defoliation
Velpar - Spot	3.8	5	0	0	N/A	0	4	4
		12	0	2	1.0**	0	2	3
Velpar - Broadcast	5.4	5	0	0	N/A	0	3	3
		12	0	0	N/A	0	1	1
Spike - Spot	4.5	5	0	0	N/A	0	0	2
		12	0	0	N/A	0	0	1
Spike - Broadcast	4.7	5	0	0	N/A	0	0	3
		12	0	0	N/A	0	0	0
Control (no soil treatment)	5.0	5	0	0	N/A	0	0	1
		12	0	0	N/A	0	0	0

* Number of trees with brown cambium and total canopy defoliation.

** Height of resprout was 6.0 cm.

The Velpar broadcast treatment also caused defoliation and leaf chlorosis. After 5 months, three trees had defoliation >50% and three others showed 10 to 50% leaf loss. Twelve months after the Velpar broadcast treatment, only one tree remained heavily defoliated (>50%), and eight showed no defoliation but exhibited a flush of healthy new leaves. Chlorosis was observed on leaves of six trees treated with broadcasted Velpar after 5 months, increasing to eight trees at the end of the study. Chlorosis ranged from only a trace to 10% of the leaves in the lower part of strawberry guava canopies.

Spike. The Spike spot treatment caused no heavy defoliation (>50%) in strawberry guava, but two trees showed 10 to 50% leaf loss after 5 months. By 12 months post treatment, only one tree remained 10 to 50% defoliated; the other nine appeared completely recovered. No leaf chlorosis was observed in this treatment.

The Spike broadcast treatment affected three guava trees with 10 to 50% defoliation after 5 months. By 12 months, none of the ten trees showed any defoliation or chlorosis.

Control. Only one untreated control tree lost approximately 10% of its leaves 5 months into the study, but it had completely recovered after 12 months. The 10 control trees exhibited no chlorosis during the study; all bore healthy leaves and a new flush of growth at the 12-month monitoring.

EFFECTS ON NATIVE PLANTS

Eighteen native plant species were monitored for a year in plots surrounding soil-treated strawberry guava, but only nine of these were widespread enough to occur in all treatments.

Trees and Shrubs. Significant losses of koa, ʻōlapa, and ʻalani were noted in soil treatments over the year of monitoring (Table 5). Decreases in all three species were greater in Spike treatments than in the Velpar plots or the control. Koa and ʻōlapa losses were primarily in the 1 to 3 and >3 m height classes, while most ʻalani that died or disappeared were in the 0.1 to 1 and >1 to 3 m categories. ʻŌhiʻa also decreased in the Spike spot treatment, but this loss was not significantly different from changes in the other treatments. The two most common shrubs, pūʻahanui and ʻōhelo, exhibited small decreases in both Spike and Velpar treatments; these changes were not significant.

Ferns and Herbs. The only abundant native herbaceous plants on the soil application test site were tree ferns and ʻalaʻala wai nui. Hāpuʻu ʻiʻi numbers increased or stayed the same in herbicide plots, but losses of hāpuʻu pulu (*Cibotium glaucum*) were observed in both Spike treatments and the Velpar broadcast plots. Differences in tree fern numbers were not significant among the soil treatments and the control. ʻAlaʻala wai nui numbers decreased in the Spike broadcast and Velpar plot treatments, but these changes were not significant.

Although not widespread enough to permit thorough analysis, three terrestrial ferns showed losses in Spike treatments but remained the same or increased in the other treatments: pahole and two species of ʻamaʻu (*Sadleria pallida* and *S. cyatheoides*).

Table 5. Results of Kruskal-Wallis tests comparing the change in number of nine native plant species among five soil treatments.

Species (Common Name)	Life Form	N*	Chi-sq	P
Acacia koa (koa)	tree	24	10.006	0.0403**
Broussaisia arguta (pūʻahanui)	shrub	14	1.427	0.6993
Cheirodendron trigynum (ʻōlapa)	tree	18	10.334	0.0352**
Cibotium chamissoi (hāpuʻu ʻiʻi)	fern	12	3.830	0.2804
Cibotium glaucum (hāpuʻu pulu)	fern	18	9.024	0.0605
Melicope spp. (ʻalani)	tree	32	19.265	0.0007**
Metrosideros polymorpha (ʻōhiʻa)	tree	16	5.725	0.2206
Peperomia spp. (ʻalaʻala wai nui)	herb	12	5.374	0.2510
Vaccinium calycinum (ʻōhelo)	shrub	5	4.000	0.2615

* N = sample size; Chi-sq = chi-square approximation from Kruskal-Wallis non-parametric test; P = probability.

** Treatments significantly different at the 95% level of confidence.

DISCUSSION AND SUMMARY

Cut-stump and soil applications were emphasized in this test, because most of the strawberry guava plants above 610 m (2,000 ft) elevation in Kīpahulu Valley were small-diameter, multiple-trunked trees. This typical clumped growth form makes the use of other application techniques, such as frilling, notching, or drilling, more difficult and time-consuming. While cut-stump application of herbicide may be fast and practical when guava trees are small, in a high rainfall area such as Kīpahulu, there is risk of rooting in the cut slash. In this study, the slash from the cut-stump treatment, 21 months old, was still alive and had produced roots at 10% of the cut strawberry guava trees. At an additional 20% of cut guava trees, the slash from the treatment remained green and had produced new shoots but had not rooted after 21 months.

Among the cut-stump treatments, undiluted Garlon 4 killed 30% more quava than the next-most effective treatment. However, undiluted Garlon 4 was not significantly better at suppressing resprouts than most of the other cut-stump treatments. Only 5% Garlon 3A, citrus oil, and the water control were completely inadequate as treatments for strawberry guava. The four other cut-stump treatments were moderately effective, killing between 40 and 50% of treated guava stumps. In the undiluted Garlon 4 treatment and four other cut-stump treatments, "large" trees $\geq$ 5 cm diameter at the base were more likely to survive than "small" trees 1 to 4 cm in diameter.

The determination of percent kill by evaluating cambium vigor or death was particularly difficult in this study. A small percentage of strawberry guava stumps displayed brown cambium at multiple sites and appeared dead after 14 months but were subsequently found to have live green cambium at the final 21-month monitoring. Guava stumps that seemingly recovered cambium vigor amounted to 5 to 20% of the trees in the six cut-stump treatments. For example, 3 of 20 stumps treated with undiluted Garlon 4 (the most successful treatment) recovered vigor in the interval between the 14- and 21-month monitorings, and 4 of 20 stumps treated with undiluted Garlon 3A showed a change from brown to green cambium in the same time period. In other studies involving different alien wody species (Santos *et al.* 1991, Cuddihy *et al.* 1991), a monitoring period of two years was considered sufficient to determine percentage kill and herbicide effectiveness. The eventual fate of the treated guava in this study is not known with certainty, but it is assumed that stumps displaying brown cambium and no live shoots (resprouts) 21 months after treatment were dead. It is also possible that herbicide-treated stumps with green cambium that had not resprouted after 21 months might eventually die. Future studies of strawberry guava control methods in Kīpahulu may require several years to accurately determine treatment efficacy.

When properly applied to strawberry guava stumps or trunks, Garlon 4 and Garlon 3A do not seem to pose a significant risk to the common native plants of Kīpahulu Valley. Observed losses of native woody plants occurred primarily in the cut-stump treatments with undiluted Garlon 3A and Garlon 4, and were not statistically significant for 14 species. The two woody species that showed significant decreases appeared to be affected by several dilute herbicide treatments. 'Alani disappeared from plots around guava treated with 5% Garlon 3A, 5% Garlon 4, or Garlon 4, while manono decreased in plots of the 5% Garlon 3A and citrus oil treatments. The only other significant loss detected in cut-stump treatments was a fern species (*Asplenium* sp.) in the water control; trampling or mechanical damage was probably responsible for this loss.

Garlon was selected as the primary herbicide in this test because it had been identified as highly effective on strawberry guava in a previous test in Hawaii Volcanoes National Park (Kageler *et al.* 1986). Other herbicides tested on cut strawberry guava in Hawaii Volcanoes National Park have included Tordon 22K (picloram), Tordon RTU (picloram and 2,4-D), and Roundup (glyphosate). Both undiluted Tordon 22K and Tordon RTU controlled 100% of treated guava in one test at a Park site near the coast (Kageler *et al.* 1986), but in a second trial including coastal and upland sites to 1,220 m (3,900 ft) elevation, Tordon 22K achieved only 21% control after two treatments (Kageler 1987). Undiluted Roundup was found to be ineffective as a cut-stump treatment on strawberry guava (Kageler 1987). In an earlier test of herbicides on strawberry guava in lower Kīpahulu Valley, cut-stump treatments with undiluted Roundup, Tordon 22K, Broadside (monosodium methanearsonate and cacodylic acid), or diesel oil were all unsatisfactory (Gardner 1980).

While two Tordon formulations (22K and RTU) have been used successfullly in Hawaii Volcanoes National Park to control strawberry guava over limited areas (50-100 ha), the potential for leaching and mobility in water

(Humberg *et al.* 1989) have caused National Park Service personnel to seek alternative herbicides (J.T. Tunison, pers. comm. 1991).

In the present study, undiluted Garlon 3A was also tested as a frill treatment on larger trees, averaging 11 cm (4.3 in.) in basal diameter. This treatment killed guava as effectively as all cut-stump treatments except undiluted Garlon 4. By contrast, the basal bark application of 50% Garlon 4 did not kill any treated strawberry guava. Other researchers have also found Garlon (triclopyr) to be unsatisfactory as a basal bark treatment for strawberry guava. In one test utilizing the basal bark application of herbicide, several dilutions of triclopyr (2, 4, and 8%) were rated as inadequate for guava control (Motooka *et al.* 1988). A basal bark application of 2,4-D was also tested; it caused virtually no negative symptoms on guava in one trial (Motooka *et al.* 1988) but completely defoliated 50% of treated strawberry guava in another test (Motooka and Nagai 1985).

Notching, a technique similar to frilling but involving one or more discontinuous cuts into a stem, has also been used to apply herbicide to strawberry guava. Motooka and Nagai (1983, 1985) found that picloram (Tordon 22K) applied to notches was very effective against strawberry guava in relatively dry areas (90% kill), but percentage kill was much lower (65%) in a high rainfall area (Glenwood, on Hawai'i Island). Results with glyphosate (Roundup) applied to notches were variable and somewhat opposite to those with picloram. Glyphosate killed 86 to 95% of notched strawberry guava at two wet sites on Hawai'i Island (Glenwood and Keopua) (Motooka and Nagai 1983), but only 33% of glyphosate-treated trees died at a drier site at Kealakekua on the same Island (Motooka and Nagai 1985).

Soil treatments with Velpar (hexazinone) and Spike (tebuthiuron) were not effective in controlling strawberry guava in the present study. Both herbicides used as soil treatments in this study were applied at the highest rate allowed by their labels. Strawberry guava showed slight sensitivity to Velpar, but Spike had virtually no negative impact on the tree. The manufacturer of Spike (Elanco) does not recommend the herbicide for use in areas with greater than 25 in. annual rainfall. Several native tree and shrub species showed dramatic decreases in Spike-treated plots. Three tree species exhibited losses in Spike plots significantly greater than those in Velpar or control plots. Neither of the tested soil treatments appears to have promise in strawberry guava control in high rainfall areas such as Kīpahulu Valley.

The recommended treatment for strawberry guava is the cut-stump application of undiluted Garlon 4. Caution must be taken to stay within the labelled rate of herbicide per acre (1.5 qt/acre). If possible, treatment should be carried out on sunny days. Further research on other application techniques, such as notching, may be warranted. If notching or frilling were used to apply herbicide, the risk of cut guava shoots sprouting and taking root would be lessened. We recommend that further testing be done on large strawberry guava trees with the frill or notch application of Garlon 4 or Garlon 3A to find the lowest effective concentration. As other researchers have had success in killing strawberry guava with Roundup applied to notched trunks, this herbicide and application technique should be tested in Kīpahulu Valley.

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