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Site Preparation Affects Survival, Growth of Koa on Degraded Montane Forest Land

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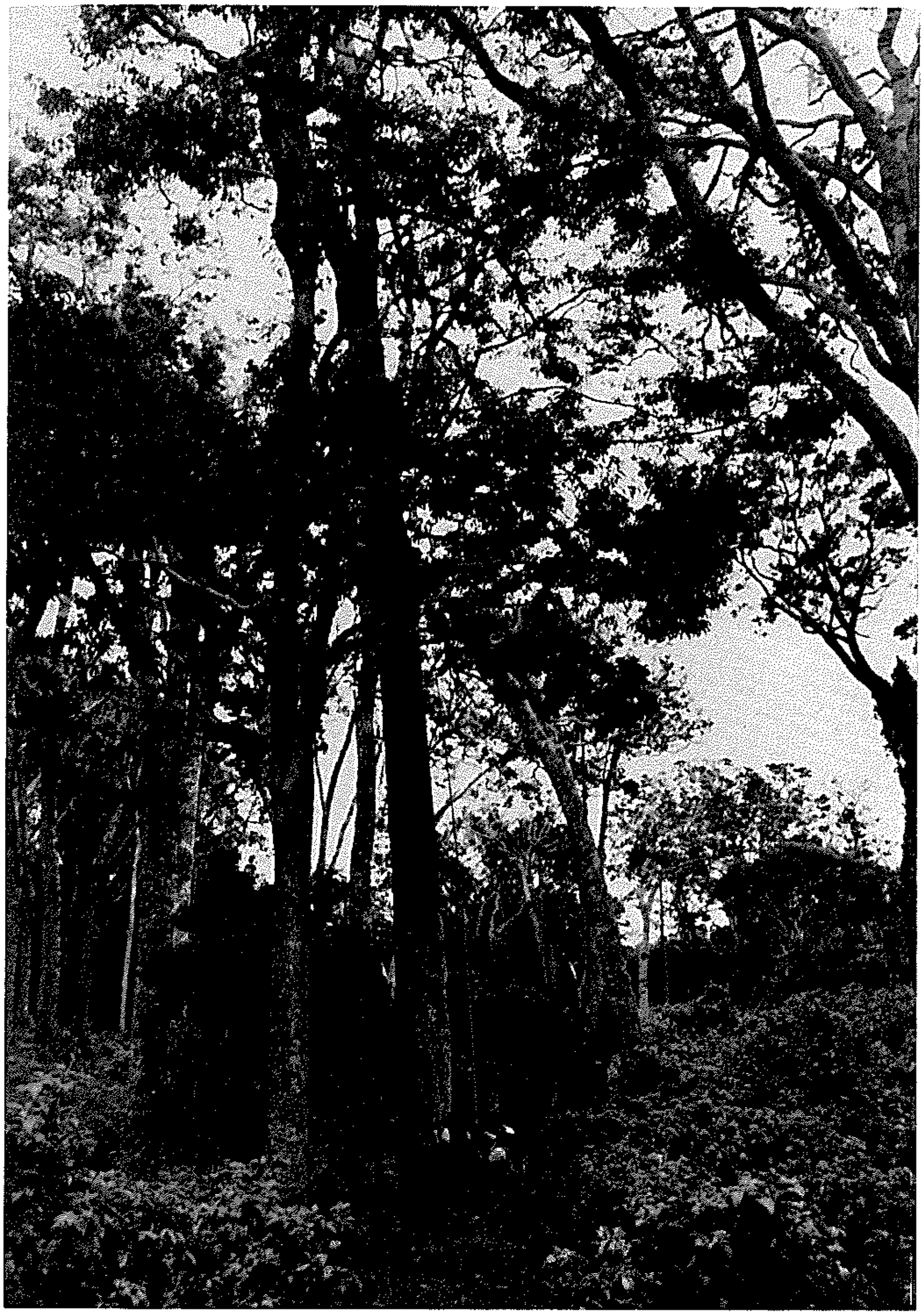

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Banana poka vines *(Passiflora mollissima)* and kikuyu grass *(Pennisetum clandestinum)* can limit koa *(Acacia koa)* reforestation in Hawaii. Performance of planted koa seedlings was studied in relation to type of site preparation: broadcast spraying of Roundup herbicide at three rates (2.02, 4.05, and 6.07 kg active ingredient per hectare) and hand scalping vegetation from each planting spot. One year after planting, survival and growth of koa seedlings were significantly greater in plots sprayed with a heavy dose of Roundup than in control plots. Ten-year survival and height were significantly greater for the heavy-dose treatment than for the scalp treatment, but none of the trees in the control treatment were alive. Site preparation must control competing vegetation over the entire planting area, to give koa a competitive edge during establishment.

Retrieval Terms: Acacia koa, Passiflora mollissima, Pennisetum clandestinum, competition, Hawaii, reforestation

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IN BRIEF . . .

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Restoring native, mixed-species forests on degraded montane lands of Hawaii has become a desirable goal for Federal, State, and private land owners. For some owners the main objective is to restore habitat for recovery of threatened and endangered forest species. For others the main objective is to grow commercial-size koa and other high-quality native hardwoods. And for still others the objective is to reestablish the flow of multiple, forest-derived benefits. Regardless of the objective for restoring native forests, owners share a common concern—what can be done to establish and speed development of such forests?

The question is difficult to answer partly because many aggressive introduced plants and animals have become naturalized; they compete intensely with native forest species. Cattle grazing is incompatible with maintenance and restoration of native forests. Koa *(Acacia koa)*, one of the two main overstory trees in Hawaiian forests and a key species in reforestation plans, is particularly vulnerable to damage by cattle. Banana poka *(Passiflora mollissima)* and kikuyu grass *(Pennisetum clandestinum)* are two introduced plant species that can limit reforestation success in Hawaii.

This paper reports the results of alternative types of site preparation on survival and growth of planted koa seedlings in an area heavily infested with banana poka and kikuyu grass. A randomized complete block design was used to study the effects of (a) broadcast spraying of Roundup herbicide at three rates (2.02, 4.05, and 6.07 kg active ingredient per hectare) and (b) hand scalping of vegetation from a 0.3 square-meter area around each planting spot.

The heavy-dose herbicide treatment most effectively controlled competing vegetation during seedling establishment. One year after planting, 74 percent of the seedlings were above competing vegetation in the heavy-dose treatment, only 22 percent were bent over or covered by banana poka vines, and 95 percent had acceptable to high vigor. In contrast, none of the seedlings were above competing vegetation in the control, 82 percent were bent over or covered by banana poka vines, and only 45 percent had acceptable to high vigor. This difference in degree of competition control resulted in significantly greater 1-year survival, height, and relative growth rate of koa seedlings in the heavy-dose treatment than in the control.

Ten years after planting, none of the trees in the control treatment were alive. Ten-year survival, total height, height to crown, and height to first major fork were significantly greater for the heavy-dose treatment than for the scalp treatment. Type of treatment did not significantly affect 10-year mean stem diameter, which ranged from 8.7 to 12.4 cm at breast height.

Successful establishment of koa on sites occupied by banana poka and dense stands of kikuyu grass depends on adequate site preparation to control competition. A heavy dose of Roundup proved an effective means of imposing such control. If a manager decides to use herbicide, we recommend that the entire planting area be treated rather than just the small area around each planting spot. Disk plowing of grasslands is an alternative form of site preparation that has been used successfully on the Island of Hawaii. We also recommend that planted areas be periodically weeded for 5 to 10 years to keep banana poka vines from damaging the developing stands.

INTRODUCTION

More than 1,000 hectares of cattle pasture and degraded montane forest on the Island of Hawaii may be planted with koa *(Acacia koa)* during the 1990's to accelerate restoration of native mixed-species forest habitat for threatened and endangered birds (i.e., the Hakalau Forest National Wildlife Refuge) or to help build an economically viable timber resource. Koa was selected for planting because (a) it is an important component of habitat for endangered forest birds, such as the akiapolaau *(Hemignathus munroi)*, Hawaii creeper *(Oreomystis mana)*, and akepa *(Loxops coccineus)* (Scott and others 1986); (b) it is a nitrogen-fixing, pioneer species in disturbed habitats during secondary succession, thus creating conditions favorable to reestablishment of other native plants (Mueller-Dombois and others 1981); and (c) its commercial value exceeds that of all other native Hawaiian trees (Skolmen 1968).

The areas targeted for reforestation—portions of the eastern flank of Mauna Kea between 1,500- and 2,000-m elevation—supported koa and ohia-koa forests before 1800. But with the advent of cattle and sheep ranching in the mid-1800's, extensive tracts of closed-canopy forests were converted to open pastures and grazed woodlands (Cuddihy and Stone 1990). Forests adjacent to the ranches were degraded by the frequent incursion of livestock.

Two of the more formidable obstacles to successful reforestation are cattle grazing and interspecific competition. Cattle grazing is incompatible with koa reforestation, especially during stand establishment and early development. Koa reproduction is completely suppressed by cattle grazing (Baldwin and Fagerlund 1943, Mueller-Dombois and others 1981, Scott and others 1986, Whitesell 1964). Cattle prefer young koa to grass (Skolmen 1990). Saplings are straddled and trampled by cattle in their quest for succulent foliage (Whitesell 1964), and both saplings and pole-size koa are barked by cattle. No one knows how long cattle must be excluded from a koa reforestation site before the trees become resistant to these types of injury. However, managers generally agree that cattle no longer damage koa once the bark becomes thick, rough, and scaly (Horiuchi and Wakida 1989).

Numerous grass species have been introduced to improve forage quality. Some of these grasses form thick, dense stands that compete with woody seedlings for water, nutrients, and light; kikuyu grass *(Pennisetum clandestinum)* is one of these. We suspect that, of the grasses, it poses the greatest threat to regeneration of native forest species. However, the seriousness of the threat from kikuyu grass is still open to question.

Banana poka *(Passiflora mollissima)*, an aggressive introduced vine, is also a serious threat to reforestation. Readily dispersed by feral pigs *(Sus scrofa)* and introduced fruit-eating birds (Cuddihy and Stone 1990), poka shrouds seedlings, saplings, and even moderately large adult trees in a blanket of vines. Reduced growth, lodging, and breakage of koa trees result.

Successful reforestation will probably require development and application of a silvicultural plan that addresses issues such as seed source (location and quality of the parent tree), nursery practices, site preparation, planting and replanting practices, post-planting maintenance practices, and protection against animal damage. Research can provide information to help develop reforestation plans.

This paper reports the results of site preparation on survival and growth of planted koa seedlings in an area heavily infested with kikuyu grass and banana poka.

STUDY AREA

The mesic study site lies on the northeast slopes of Mauna Kea at 1,550 m elevation in the Humuula section of the Hilo Forest Reserve on the Island of Hawaii. Median annual rainfall is about 2,300 mm (Division of Water and Land Development 1982). The period May through September is the driest season—only 25 percent of the annual rainfall occurs during the 5-month period. Mean annual temperature is about 15 °C (Division of Water and Land Development 1970). Formed in volcanic ash, the well-drained silt loam soil is a thixotrophic, isomesic, Hydric Dystrandept of the Puu Oo series (Sato and others 1973). These soils are high in surface layer organic matter and, generally, they have a large capacity to fix phosphorus into forms unavailable to plants. The topography is undulating with 6 to 12 percent slopes.

The forest is an open koa-ohia type. Mature and senescent emergent koa trees dominate the overstory. Scattered ohia-lehua *(Metrosideros polymorpha)*, pilo *(Coprosma* spp.), and tree fern *(Cibotium* spp.) are also present. Kikuyu grass, banana poka, the native Hawaiian raspberry *(Rubus hawaiiensis)*, and blackberry *(Rubus argutus)* dominate the shrub and herbaceous layers. Velvet grass *(Holcus lanatus)*, puu-lehua grass *(Microleana stipoides)*, knotweed *(Polygonum glabrum)*, nipplewort *(Lapsana communis)*, bracken *(Pteridium aquilinium)*, and laukahi *(Dryopteris paleacea)* are also common ground cover species.

We chose this degraded forest area because it was typical of other portions of the windward side of Mauna Kea targeted for koa reforestation and it was easily accessible. The study area had been grazed in the past, but at the time of this study all cattle had been removed. Feral pigs were common. Kikuyu grass and banana poka infestations were heavy, and natural koa regeneration was sparse.

METHODS

We conducted a preliminary study to determine which herbicide[1] to use in the chemical treatments—Roundup[2] [N-(phosphonomethyl)glycine] or a mixture of Dowpon M[2] [2,2-dichloropropionic acid] and Karmex[2] [3-(3,4-dichloro-phenyl)-1,1-dimethylurea]. Roundup was tested at two concentrations—4.05 and 8.10 kg active ingredient (a.i.) per hectare. Dowpon and Karmex were tested in three mixtures—8.29 kg a.i. Dowpon and 8.96 kg a.i. Karmex per ha; 8.29 kg a.i. Dowpon and 16.8 kg a.i. Karmex per ha; and 12.43 kg a.i. Dowpon and 17.92 kg a.i. Karmex per ha. Each herbicide was sprayed on a separate set of three 5- by 5-m test plots. The percent loss of live banana poka cover and grass cover was estimated 3 months after spraying.

Data obtained in the herbicide screening test was subjected to one-way ANOVA and the Bonferroni method of multiple comparisons (Neter and Wasserman 1974) using a family Type I error rate of no more than 0.025. Results indicated that Roundup was more effective at controlling banana poka than any of the Dowpon/Karmex mixtures *(table 1)*. Roundup was as effective at controlling grasses as the Dowpon/Karmex mixtures. On the basis of these results, we selected Roundup for use in the main study.

We used a randomized complete block design to study the effect of chemical and mechanical site preparation on survival and growth of koa seedlings. Three blocks, each large enough to contain five 10- by 10-m treatment plots and their associated 2.5-m buffer strips, were delineated in an area that we believed was representative of the upper portion of the Humuula forest. Two of the blocks lay side-by-side; the third block lay about 75 m north of the others. All three blocks were in the open and not shaded by nearby mature koa trees. The blocks were fenced to exclude cattle and feral pigs.

Five treatments were randomly assigned to plots within each block—three chemical treatments, one mechanical treatment, and a control treatment. The chemical site preparation treatments were Roundup applied at three rates: 2.02 kg a.i. per ha (light dose), 4.05 kg a.i. per ha (moderate dose), and 6.07 kg a.i. per ha (heavy dose). Herbicides were applied to entire plots, not just to planting spots. The mechanical treatment involved hand scalping of the vegetation in a 0.3 square-meter area around each planting spot.

Koa seedlings were grown at the Division of Forestry and Wildlife, Central Tree Nursery. The seed collection area was about 2.5 km from the study site and located within the Laupahoehoe section of the Hilo Forest Reserve between 1,400 to 1,800 m elevation. Planting was done in February 1978, 8 weeks after herbicides were applied. Sixty-four dibble seedlings were planted in each treatment plot on a square spacing of 1.25 m. Scalping was done at time of planting. No weeding was done during the first year of growth.

Only the 36 inner trees per plot were used to evaluate treatment effects. Height, vigor class (high, acceptable, low, or dead), and position with respect to surrounding vegetation (shorter, same height, or taller) were recorded for each seedling at time of planting, and at 3, 6, and 12 months after planting. Heights were measured from the root collar to the terminal irrespective of the lean of the tree.

No additional data were collected until October 1987 when we measured height, diameter at breast height (1.4 m above ground), disease class (yes or no), height to the base of live crown, and height to the first major fork. During the intervening years, banana poka vines and other overtopping vegetation were cut from surviving trees several times. No other weeding or maintenance was done.

[1]This paper neither recommends the pesticide uses reported nor implies that the pesticides have been registered by the appropriate governmental agencies.
[2]Trade names or commercial brands are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Table 1—*Average percent change of banana poka and grass cover three months after applying herbicides in herbicide screening trials*[1]

Treatment (*kg a.i./ha*[2])	Type of cover	
	Banana poka	Grasses
	percent	
Roundup:		
4.1	-70 (8)	-97 (0)
8.1	-86 (4)	-97 (0)
Dowpon/Karmex mix:		
8.3:9.0	0 (0)	-95 (1)
8.3:16.8	-34(18)	-99 (1)
12.4:17.9	-23(14)	-100 (0)
Control	+19(10)	0 (0)

[1]Standard errors of the means (to the nearest percent) are shown in parentheses.
[2]kg a.i./ha = kilograms of active ingredient per hectare.

DATA ANALYSIS

Differences in survival were evaluated at one year and ten years after planting using one-way ANOVA with three observations per treatment. Proportions were subjected to angular transformation for analysis. Because the 36-tree plot was the sampling unit, not the individual seedling, the treatment-block interaction was used as the error term for hypothesis testing in this and all other ANOVA's. Differences among treatment means were evaluated by Tukey's method of multiple comparisons. Mean survival data and associated standard errors in arcsine units were back-transformed for presentation.

Differences in mean stem height were examined one year after planting using two-way ANOVA. The factors were treatment and block. Differences among treatment means were evaluated using Tukey's method of multiple comparisons. Because of differences in mortality, there were an unequal number of seedlings per cell.

The preceding analysis could not be used with the tenth-year height data because some experimental blocks had no survivors (e.g., none of the trees in control plots survived). Instead, differences in heights among treatments were evaluated using the Games and Howell procedure for multiple pairwise comparisons (Games and Howell 1976). The Bonferroni t statistic (Bailey 1977) was used as the critical value for rejecting the null hypothesis. Degrees of freedom were calculated using the Satterthwaite approximation (Games and Howell 1976). There were six comparisons. Each comparison was done at a significance level that achieved an overall Type I error rate of at most 5 percent.

Differences in mean stem diameter at breast height were evaluated for the tenth year only. The Games and Howell procedure was used to assess treatment effects.

Periodic height growth of the seedlings during the first year after planting was examined using mean relative growth rate. Height data for the periods 0 to 3 months, 3 to 6 months, and 6 to 12 months were used to calculate relative growth rate (RGR) based on the formula

$$RGR = (H_{t_2}/H_{t_1})^{1/(t_2-t_1)} - 1 \qquad \text{Eq. 1}$$

where H_{t_1} and H_{t_2} are stem heights at time t_1 and t_2, respectively. RGR can be interpreted as the rate of interest on the capital, that is, the rate of height growth per unit of initial height. Units for RGR are centimeters of growth per centimeter of initial stem height per month or percent height growth per month.

Mean relative growth rate ($\overline{RGR}_{ij}$) for a plot was calculated as

$$\overline{RGR}_{ij} = \left(\sum_{k=1}^{n_{ij}} RGR_{ijk}\right)/n_{ij} \qquad \text{Eq. 2}$$

where RGR_{ijk} is the relative growth rate for the k^{th} seedling in the j^{th} block and i^{th} treatment, and n_{ij} is the number of trees in each plot.

Treatment and block effects were examined using the SAS general linear models (GLM) procedure (SAS Institute 1985). Only those seedlings that were alive 12 months after planting were used to calculate mean RGRs. Differences among treatments were tested using Tukey's multiple comparison procedures. Each comparison was done at a significance level that achieved an overall Type I error rate of at most 5 percent.

RESULTS

Survival

Average seedling survival one year after planting ranged from a high of 85 percent (±8.4 percent $s_{\bar{x}}$) for plots sprayed with a heavy dose of Roundup to a low of 30 percent (± 14 percent $s_{\bar{x}}$) for control plots *(fig. 1)*. The improvement in first-year survival in plots sprayed with a heavy dose of herbicide was statistically significant. Survival in herbicided plots treated with moderate and light doses of Roundup and in scalped plots was not significantly different from that in control plots.

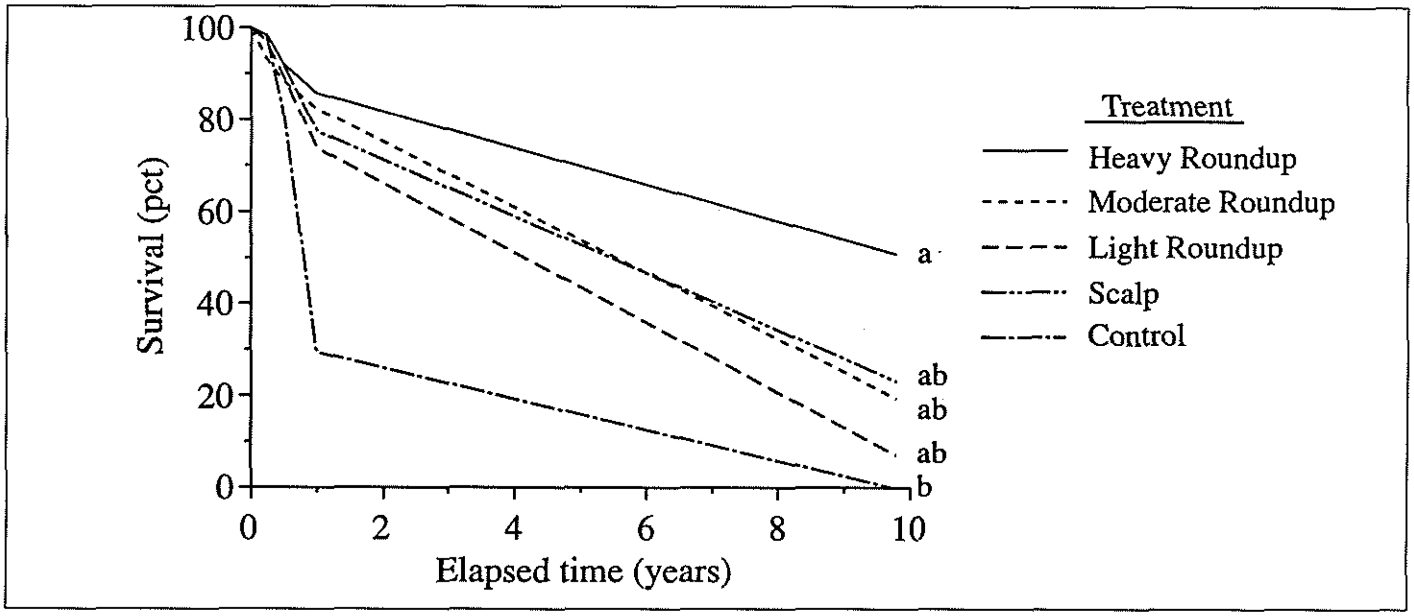

Figure 1—Survival of planted koa as a function of elapsed time since planting and type of site preparation treatment. Ten-year means followed by the same letter are not significantly different at the overall significance level of 0.05 (Bonferroni t-test).

Ten years after planting, 51 percent of the koa in plots initially sprayed with a heavy dose of Roundup were still alive *(fig. 1)*. In contrast, none of the koa in control plots were still alive. The heavy herbicide treatment was the only one that significantly improved 10-year survival compared with the control. In *figure 1*, the moderate herbicide treatment and the scalp treatment appear to have better survival than the control. But large variability among replicates and small sample size prevented detection of significant treatment effects *(table 2)*.

We attributed the improvement in survival mainly to the beneficial effects of site preparation, not to the beneficial effects of plot maintenance. All plots were weeded at identical times and with equal thoroughness. All trees should have benefited from weeding equally, regardless of site preparation treatment.

Differences in site preparation affected how often weeding was needed. For example, weeding was needed most frequently in the control treatment and least frequently in the heavy herbicide treatment. But weeding was not done on an as-needed basis. Rather it was done infrequently and at irregular intervals. In the interim, competing banana poka vines tended to overwhelm koa in all except the heavy herbicide treatment. We believe that the initial competitive edge conferred on trees in the heavy herbicide treatment lasted several years. Whatever competitive edge was given to trees in the other site preparation treatments was not as longlasting. Hence, trees growing in plots with such treatments were adversely affected by competition between weedings.

Stem Height

One year after planting, the mean height of koa seedlings ranged from 0.6 m (± 0.1 m $s_{\bar{x}}$) in scalped plots to 1.7 m (± 0.1 m $s_{\bar{x}}$) in heavy-dose plots. Trees planted in plots sprayed with heavy or moderate doses of Roundup were significantly taller than those in control or scalped plots *(fig. 2)*.

Ten years after planting, the mean height of surviving koa trees in the heavy-dose plots (8.4 m) was still greater than in the scalped plots (5.8 m); the difference was significant *(table 2)*. A similar comparison between the heavy-dose and control treat-

Table 2—*Mean[1] survival, tree height, diameter at breast height (1.4 m), height to crown, and height to first fork of koa trees 10 years after planting, by treatment[2]*

Treatment	Sample size	Survival	Height	Stem diameter	Height to . . . Crown	Fork
		—pct—	—m—	—cm—	—m—	
Roundup:						
Heavy dose	3	50.8 a (±19.2)[3]	8.4 a (±1.7)	12.0 a (±2.9)	4.8 a (±1.5)	4.7 a (±1.3)
Moderate dose	2	19.5 a[4] (±72.1)	5.9 ab (±6.7)	8.7 a (±12.2)	2.8 ab (±3.7)	3.3 ab (±2.9)
Light dose	2	7.4 a[4] (±44.6)	7.5 ab (±17.6)	12.4 a (±37.5)	2.8 ab (±3.2)	3.7 ab (±3.2)
Scalp	3	23.7 a (±5.9)	5.8 b (±2.1)	10.5 a (±6.1)	2.0 b (±0.8)	2.8 b (±1.1)

[1]Means within a column followed by the same letter do not differ significantly at the 0.05 level of statistical significance (Bonferroni t-test).

[2]No koa trees in the control treatment survived.

[3]The 95 pct confidence intervals are in parentheses. Confidence interval = mean ± (t)($s_{\bar{x}}$); alpha ≤ 0.05;

$$df = n - 1;\ s_{\bar{x}} = \left(\sum_{i=1}^{n} s_{\bar{x}_i}^2/n\right)^{0.5};\ mean = \sum_{i=1}^{n} x_i/n.$$

[4]Mean percent survival based on n = 3.

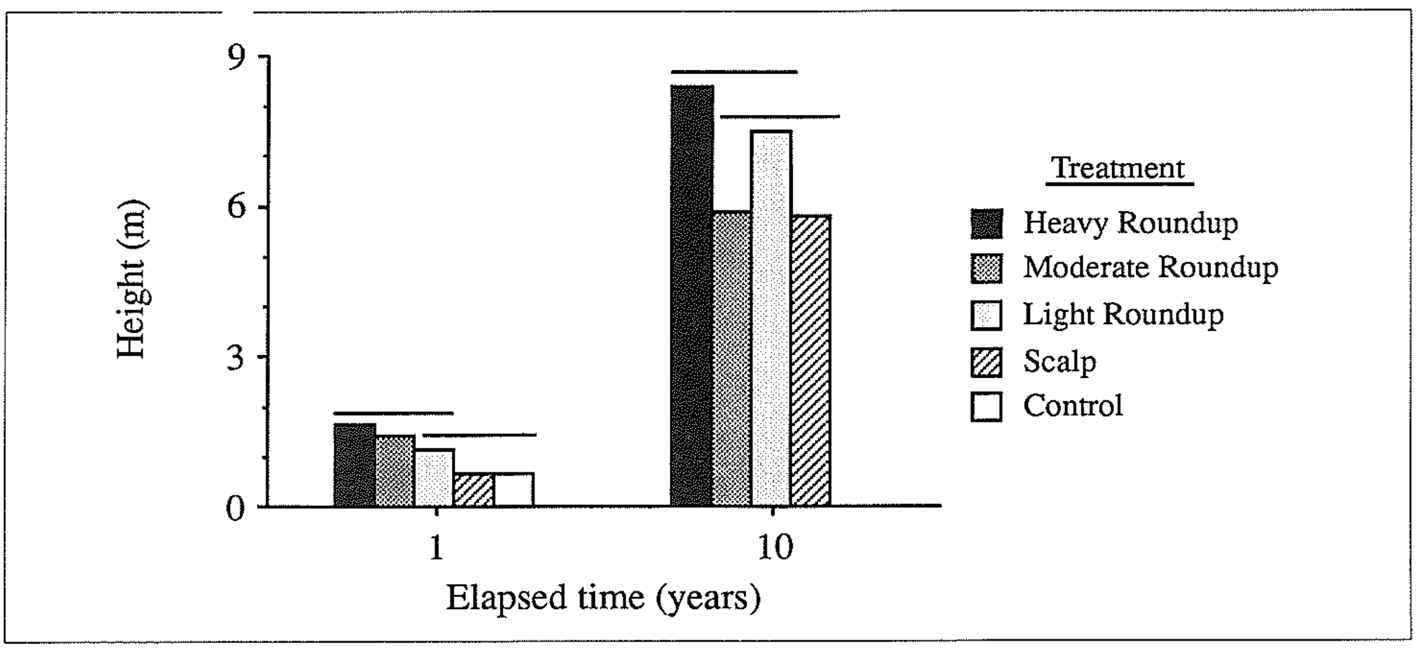

Figure 2—Average height of koa trees one year and ten years after planting, by type of site preparation treatment. No trees in the control treatment were alive at 10 years. Treatments grouped under a common horizontal line are not significantly different at the overall significance level of 0.05 (Bonferroni t-test).

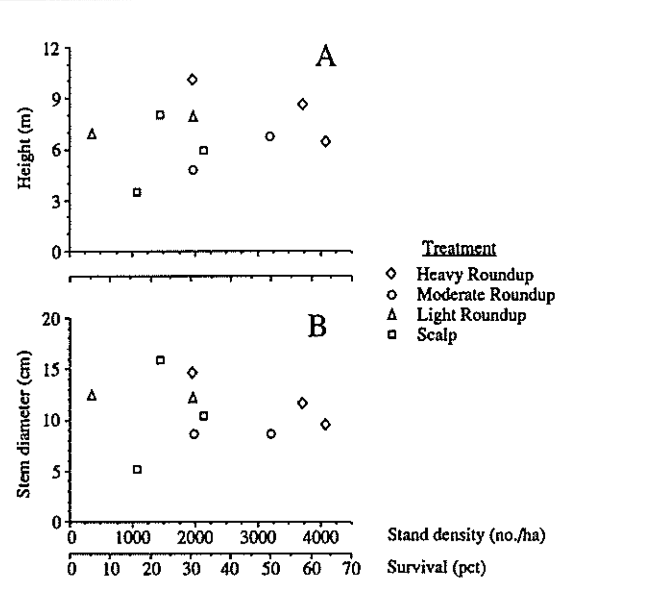

Figure 3—Relationship between percent survival (stand density) and mean tree height and mean stem diameter at breast height (1.4 m) of koa ten years after planting, by type of site preparation treatment.

ments could not be made because all trees in control plots died before our last measurement. None of the other differences among treatments were statistically significant *(fig. 2)*.

Generally, tree height is unaffected by stand density, over a wide range of densities (Spurr and Barnes 1980). We found no evidence that height of 10-year-old trees was affected by survival, i.e., stand density *(fig. 3A)*, except in the heavy herbicide treatment. In that treatment, average height of koa was negatively correlated with survival. Such negative effect of stand density on tree height normally occurs in only very dense stands.

Stem Diameter

Ten years after planting, mean stem diameters ranged from 8.7 cm in moderate-dose plots to 12.4 cm in light-dose plots *(table 2)*. There was considerable variability in diameter at breast height (dbh) within treatments. For example, the dbh of trees growing in scalped plots varied from 0.6 to 27.9 cm. Differences in mean dbh among treatments were not significant at ten years of age, partly because of this large variability.

We found no consistent effect of survival (i.e., stand density) on stem diameter of 10-year-old trees *(fig. 3B)*. Generally, the mean diameter of trees in a stand decreases nonlinearly with increasing stand density (Spurr and Barnes 1980). Such a relationship was evident only in plots treated with a heavy dose of Roundup.

Other Stand Characteristics

Mean height of the base of the live crown was significantly greater in plots prepared with a heavy dose of Roundup than in plots prepared by scalping *(table 2)*. The heavy-dose plots had more than twice the stem basal area of any other treatment. We believe that shade within plots treated with a heavy dose of Roundup was deep enough to cause branch death in the lowest portion of the crowns. Differences among other pairs of treatment means were not significant.

The first major fork in the trunk occurred at an average height of about 5 m in plots prepared with a heavy dose of Roundup. In scalped plots, forking occurred at about 3 m above the ground. We suspect that this statistically significant difference between the two treatments *(table 2)* was a function of survival and canopy closure. Because of relatively high survival, trees in plots sprayed with a heavy dose of Roundup were crowded, and their crowns closed early in stand development. The low light levels within these stands resulted in the death of lower branches. Thus, major forks could not develop low on the tree trunks. In contrast, the relatively low survival of trees in scalped plots created more open stands. Light levels within these stands were high enough to allow lower branches to survive and major forks to develop.

More than 70 percent of the surviving 10-year-old koa in heavy-dose, light-dose, and scalp plots showed symptoms of disease—swollen, oozing portions of the main stem, mistletoe, or fungal fruiting bodies. About 50 percent of the koa in plots treated with a moderate dose of Roundup were obviously diseased.

The prevalence of diseased trees may be unimportant in the long run. Koa stocking in an unmanaged, mature ohia-koa forest typically averages less than 35 trees per hectare. For the sake of argument, however, we will assume that 100 mature koa per hectare can be grown in a managed forest. In our study, tree density in the least stocked plot treated with a heavy dose of Roundup was 1,100 trees per hectare at 10 years. If all of the diseased trees died by the time the stand reached maturity, density would still be three fold greater than the site could support. The stand would have to suffer an additional loss of 70 percent of the healthy trees for stand density to reach 100 trees per hectare.

Relative Height Growth Rates

The first three months after planting, height growth was slow as seedlings recovered from transplant shock and adjusted to a new environment. Mean RGRs *(eq. 2)* for seedling heights were generally between 4 and 7 percent per month during that period of growth. Treatment effects were not significant *(fig. 4)*.

The second three months after planting, height growth accelerated. RGRs averaged up to 52 percent per month (heavy dose of Roundup). There were no significant differences in RGR among the three herbicide treatments nor was there a significant difference between the scalp and control treatments *(fig. 4)*. RGRs for the three herbicide treatments were significantly greater than those for the scalp and control treatments.

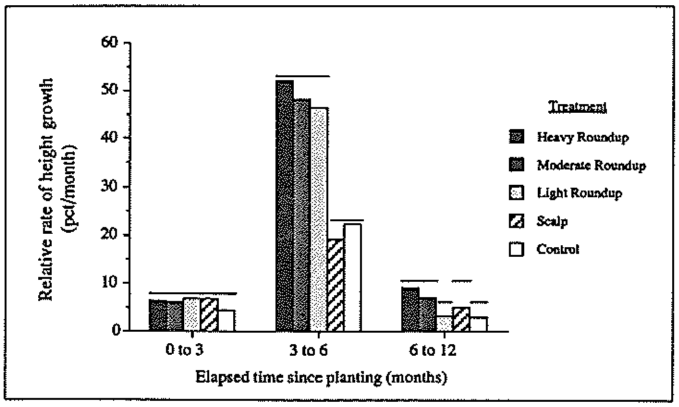

Figure 4—Mean relative rate of height growth of koa for selected intervals during the12-month period after planting, by type of site preparation treatment. Within an interval, treatments grouped under a common horizontal line are not significantly different at the overall significance level of 0.05 (Bonferroni t-test).

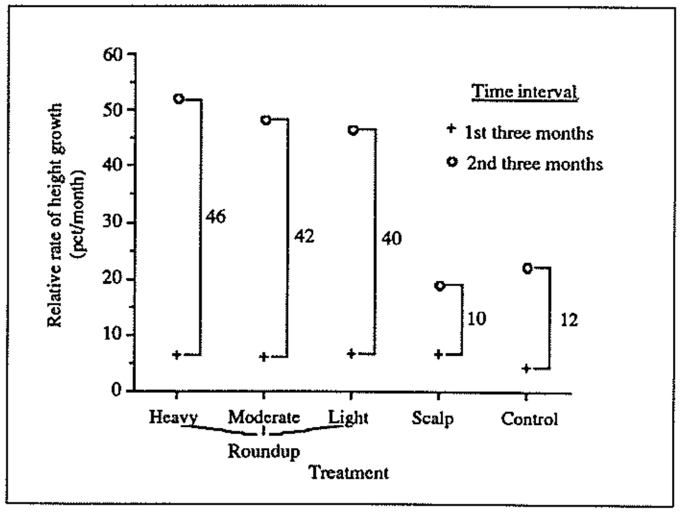

Figure 5—Magnitude of differences in mean relative rate of height growth between the first three and second three months of growth, by type of site preparation.

In all treatments, RGRs during the 3- to 6-month period were significantly greater than those during the 0- to 3-month period. The acceleration in growth was most noticeable in plots treated with Roundup. Differences in RGR between the first and second 3-month periods were as much as 4.5 times greater in plots treated with Roundup than in control or scalp plots *(fig. 5)*.

During the period from 6 to 12 months after planting, growth slowed significantly in all treatments. Seedlings in plots sprayed with a heavy dose of Roundup slowed from a RGR of 52 percent per month to less than 10 percent per month, which was the most rapid rate observed for any treatment during the 6- to 12-month period. RGRs were not significantly different among the heavy dose, medium dose, and scalp treatments nor between the light dose and control treatments for the 6- to 12-month period *(fig. 4)*.

Treatment effects on mean relative rate of height growth (percent per month) for the first 12 months after planting were as follows:

Heavy dose	Moderate dose	Light dose	Scalp	Control
17.6 a	15.6 a	13.4 ab	8.4 bc	7.6 c

where means followed by the same letter are not significantly different. It is apparent that all three herbicide treatments resulted in improved rates of height growth compared to the control. But this result must be tempered by treatment effects on survival. As noted previously, only the heavy-dose herbicide treatment significantly improved survival in comparison to that achieved in the control.

Seedling Position and Vigor

Information about seedling position relative to surrounding vegetation and seedling vigor gave us clues to help explain treatment effects on survival and early growth of 1-year-old koa seedlings *(table 3)*. In control plots, more than 80 percent of the surviving seedlings were lodged or covered with banana poka vines. None of the koa crowns was above the level of competing vegetation. As a result, only 45 percent were classed as having acceptable to high vigor. In contrast, only 22 percent of the survivors in the heavy Roundup plots were lodged or covered with poka vines; 74 percent were above competing vegetation. The net effect was that 95 percent of the seedlings had acceptable to high vigor. These data reflect the degree of competition control brought about by each treatment—heavy > medium > light ≥ scalp > control.

Block Effects

Differences in growth were observed among blocks during the first year after planting. Growth was significantly slower in block 3, which was located on a separate ridge about 75 meters away from the other two blocks. At one year of age, trees in block 3 averaged 83 cm in height; those in blocks 1 and 2 averaged 145 cm and 130 cm in height, respectively. We attribute the poorer performance in block 3 to severe competition with banana poka vines. Even from the start of the study, banana poka was more abundant in and around block 3 than in and around the other blocks.

Table 3—*Percentage of surviving koa trees one year after planting, by treatment*

Treatment	Class of surviving koa tree: Lodged or covered with banana poka vines	Above competing vegetation	Acceptable to high vigor
		percent	
Roundup:			
Heavy dose	22	74	95
Moderate dose	58	30	78
Light dose	74	6	61
Scalp	17	12	63
Control	82	0	45

MANAGEMENT IMPLICATIONS

Successful establishment of koa on sites occupied by banana poka and dense kikuyu grass depends on adequate site preparation to control competition. In this study, only heavy application of Roundup to the entire planting area sufficiently suppressed competing vegetation to give koa seedlings a competitive edge. Survival, height, and rate of growth of koa growing in plots treated with a heavy dose of Roundup were greater than achieved by koa growing in control plots.

Planting spots are often prepared by hand hoeing the surrounding ground vegetation. Where the ground vegetation is sparse, short, or slow growing, scalping has proved a sufficient method for controlling competition during seedling establishment. The site used in the present study had dense, tall, rapidly growing ground vegetation. Scalping provided only short-term control of competition. The deep rhizomes of kikuyu grass were not affected, and rapid regrowth occurred.

A more drastic form of scarification may be called for on sites similar to our study site. For example, disk plowing is being used to prepare planting areas in the Hakalau Forest National Wildlife Refuge. The sites are about 10 km south of our study area and at about the same elevation. Kikuyu grass and other pasture grasses are dense, but banana poka has not yet become established. With disk plowing, the soil is thoroughly turned over. Preliminary study showed that two or three passes of the disk plow reduced grass density for about 6 months.

In areas occupied by kikuyu grass and banana poka, neither mechanical nor chemical spot treatment of ground vegetation is likely to free koa seedlings from the adverse effects of competition for more than 3 months. For example, we believe that spot spraying of a heavy dose of Roundup would be no more effective than spot scalping; it is a matter of scale. Surrounding vegetation could quickly reinvade the treated areas, and poka vines rooted just outside the sprayed spots could rapidly climb into koa canopies. Treatments have to be applied to an area larger than that in the immediate vicinity of a koa seedling.

In areas infested with banana poka, site preparation alone without follow-up maintenance will not ensure long-term stand survival and growth. Even if an entire planting area were sprayed with herbicide (as done in our Roundup treatments), cleaning and weeding would be necessary to combat reinvading poka vines. A case in point is the poor performance of seedlings in block 3 of this experiment. No doubt the abundance of banana poka vines in and around block 3 created intense competition, which was not as effectively controlled by the infrequent weedings as it was in the other two blocks. The need for maintenance will lessen if and when biological control of banana poka (Markin 1989) becomes a reality.

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