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Technical Report 49

GLYPHOSATE IN THE CONTROL OF KIKUYUGRASS, AND ITS EFFECTS ON ASSOCIATED NATIVE AND NONNATIVE PLANTS IN HAWAIIAN NATIONAL PARKS

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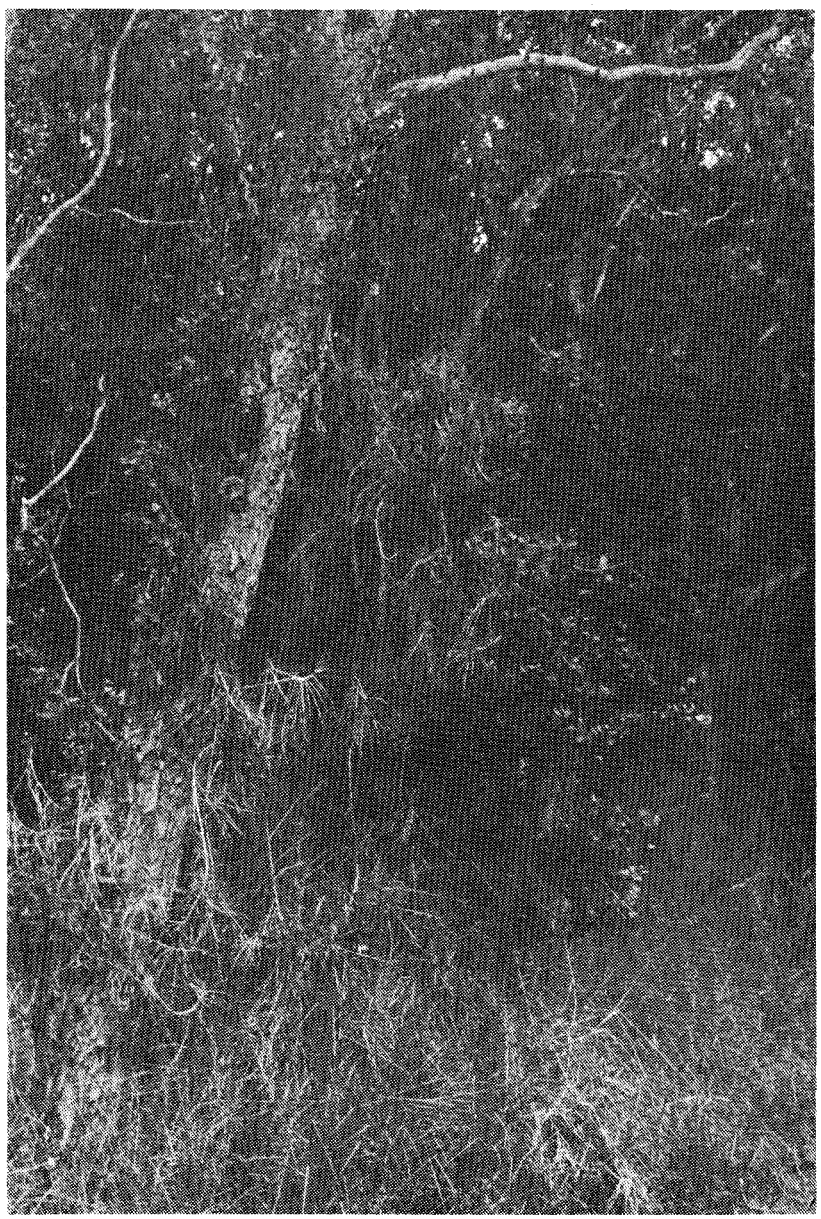
November 1983

UNIVERSITY OF HAWAII AT MANOA

A stand of healthy kikuyugrass established along a roadside in Hawaii Volcanoes National Park. Such dense stands in open, disturbed areas extend into adjacent forest margins and may cause gradual retreat of native forests by preventing seedling establishment.



Kikuyugrass closely surrounding and climbing into a native 'ohi'a-lehua tree at the forest margin. Kikuyugrass climbs readily and may cover and shade out shrubby vegetation.

A plot treated with 0.3% Roundup 6 months following application. Kikuyugrass within the plot (foreground) is dead and matted, in contrast to surrounding healthy kikuyugrass (background). Several native pa'iniu (Astelia menziesiana) plants (arrow) within the plot were apparently not affected by the herbicide and remained healthy.

Establishment of native plants 27 months after kikuyugrass was eliminated with Roundup. Left: 'ohelo (Vaccinium reticulatum). Right: kukae-nene (Coprosma ernodeoides).

Establishment of exotic ginger (Hedychium sp.) seedlings 27 months after kikuyugrass was eliminated with Roundup.

Establishment of exotic blackberry (Rubus penetrans) and thimbleberry (R. rosaefolius) 27 months after kikuyugrass was eliminated with Roundup.

ABSTRACT: Kikuyugrass (Pennisetum clandestinum) is an important range and pasture fodder grass in Hawaii, but is also a troublesome weed invading Hawaiian National Park Service areas. Kikuyugrass growth is significantly reduced by 0.05% Roundup (0.0205% glyphosate). This grass is eradicated (except for escapes shielded from spray contact in the matted grass) by 0.5% or greater concentrations. Sensitivities of other nonnative and of native plants associated with kikuyugrass varied according to the species, extent of coverage plant size, and herbicide concentration. Selectivity against kikuyugrass while preserving most associated native species was generally possible with 0.5 to 1% Roundup, especially if care is taken in application to avoid undue exposure to native plants. Control of kikuyugrass with glyphosate in natural areas is therefore a feasible and practical management approach.

INTRODUCTION

Kikuyugrass (*Pennisetum clandestinum*), a perennial rhizomatous grass native to tropical Africa, was introduced to Hawaii in 1924 for use as a ground cover and as a forage species (Hosaka 1958, Neal 1965, Rotar 1968). While kikuyugrass remains a valuable and widely used pasture and range grass in Hawaii, this species has escaped its intended range in lands adjacent to National Park Service (NPS) areas, or has been brought into NPS areas inadvertently to become well established in many of the mid-elevation (about 800 to 1,600 m) wetter regions (about 330 cm annual rainfall) of both Hawaii Volcanoes and Haleakala National Parks.

Kikuyugrass is variously regarded as a desirable or as an undesirable species in other localities (e.g. Africa, Australia, Colombia, New Zealand) as well as in Hawaii, and references may be found in the literature to both its perpetuation and its control (Cook and O'Grady 1978, Hosaka 1958, Kilavuka and Magambo 1977, Lavalue 1973, Percival 1978, Rowe and O'Connor 1975, Souza and Guimaraes 1976). The U. S. Department of Agriculture has classified kikuyugrass as a noxious weed in the contiguous 48 states and now enforces regulations preventing its importation (USDA 1981).

National Park Service objectives in preserving native ecosystems are often at variance with those of adjacent land uses (e.g. agriculture, rangeland). Acceptable control methods must therefore be confinable to the problem area such that they do not conflict with other interests. This requirement precludes the use of biological control approaches involving insects or diseases.

The presence of this nonnative (exotic) grass in NPS areas is not consistent with NPS policy which specifies that native processes are to be preserved, and that "nonnative species of plants and animals will be eliminated where it is possible to do so by approved methods which will preserve wilderness qualities" (NPS 1970). Kikuyugrass is an aggressive invader of native Hawaiian ecosystems, where it develops dense, tangled mats closely surrounding native vegetation and even extending runners into the upper branches of trees and shrubs. Such mats in older kikuyugrass stands may approach 1 meter in depth. Encroachment of this species into rainforests from adjacent open pastures and meadows is regarded by NPS resources managers as a serious threat to the integrity of such forests. Although kikuyugrass is shade intolerant and would not readily invade a forest interior, it is capable of extending into the forest margins where it smothers and kills small trees and shrubs and prevents establishment of native seedlings in these regions. The forest thereby gives way to advancing kikuyugrass stands.

Recent studies and reports (New South Wales Department of Agriculture 1978, Hanson *et al.* 1980, Londono and Cruz 1976,

Mejia and Romero 1977, Read 1978, Romero and Mejia 1976) have shown the effectiveness of the herbicide glyphosate (Anon. 1979) in kikuyugrass control under a number of environmental conditions in various countries. This compound is also among the relatively few pesticides which have been approved for use in NPS areas.

The objective of this study was to determine the effectiveness of glyphosate in the control of kikuyugrass under the environmental conditions where this species is a problem, while at the same time preserving the associated native Hawaiian vegetation types which the NPS is charged to protect.

MATERIALS AND METHODS

Twenty-four 25 m^2 treatment plots were established in a dense healthy stand of kikuyugrass which was encroaching into a native 'ohi'a-lehua (Metrosideros collina subsp. polymorpha) rainforest from a relatively open area at approximately 1,200 m elevation in Hawaii Volcanoes National Park. The mean annual rainfall was 330 cm and the mean temperature was 17 °C. The forest consisted of numerous fern, herbaceous, shrub, and small tree species in addition to 'ohi'a-lehua. Although the plots were uniformly dominated by kikuyugrass, they were selected such that, as nearly as possible, other plant species were represented as well. Buffer zones of untreated vegetation separated the plots from one another by at least 5 meters. Treated plots were compared with untreated adjacent areas of similar size and vegetation composition.

The herbicide Roundup (Monsanto Co.)* , of which 41% is the active ingredient glyphosate [N-(phosphonomethyl)glycine], was used in this study. Herbicide concentrations of 0.05 (0.0205% glyphosate), 0.1, 0.3, 0.5, 1, 2, 4, and 6% in aqueous solutions were applied in a randomized plot design consisting of three replications for each concentration.

Each plot was sprayed uniformly with 3 liters of herbicide solution with a small hand pump sprayer adjusted to deliver a fine spray under normal operating pressure. This volume was sufficient for the spray to contact most leaves in the plot to a pre-saturation level, but insufficient to result in significant runoff. Native and other exotic plants within each plot were also sprayed, with no attempt either to avoid them or to treat them preferentially. Each plot was treated only once, and the herbicide was applied at midday when leaf surfaces were dry. No rain fell for at least 4 hours following treatment. Plots were treated in the summer (June); however, the season of treatment was not considered critical to this test since kikuyugrass, as well as most other plant species in the treatment area, typically remain green and in an active state throughout the year.

*Mention of a trademark name or a proprietary product does not constitute a guarantee or warranty of the product by the U. S. Department of the Interior, and does not imply approval of it to the exclusion of other products that may also be suitable.

Treatment effects were evaluated at weekly intervals, and results were recorded at 4, 5, and 10 weeks following treatment. The plots were also observed after 6 months to ascertain recolonization trends of treated areas. Reaction severity for each species was recorded in numerical terms on a 0-5 severity rating scale which corresponded to the following categories: <10, 10-25, 26-50, 51-75, 76-95, and >95 percent mortality. The data were subjected to an analysis of variance and an F-test.

The plant nomenclature of St. John (1973) and of Porter (1972) was generally followed throughout this study.

RESULTS AND DISCUSSION

Kikuyugrass was generally sensitive to glyphosate in all concentrations applied. Greater than 95% kill of above-ground portions was obtained with concentrations of 0.5% Roundup or greater (Table 1). Since the stands of kikuyugrass within each plot were dense, some grass leaves were undoubtedly shielded from spray contact, resulting in the occasional escapes which were observed. Under the conditions of their tests, Mejia and Romero (1977) stated that rainfall within 6 hours after application significantly reduced glyphosate effectiveness, perhaps limiting its practicality in areas with frequent rainfall. However, under the conditions of the current study, herbicide solution was no longer evident after approximately 2 hours. The solution was presumed to have largely been absorbed by the plant tissue during this time since Roundup is known (personal observation) to be rapidly absorbed by tissues of other plants; however, drying on the leaf surface may also have occurred.

Kikuyugrass showed little tendency to become reestablished 6 months following treatment. The limited regeneration which did occur within the plots treated with lower Roundup concentrations (0.05 to 0.3%) arose from continued growth of the original escapes rather than from new root sprouts, indicating that roots, as well as photosynthetic rhizome parts, were killed by the single herbicide application. Reinvasion by healthy kikuyugrass from the plot margins accounted for most of the reestablishment in plots to which higher Roundup concentrations were applied. Total reestablishment from all sources was less than 10% in the 0.5% treatment plots, and decreased from 5 to less than 2% in the 1 to 6% Roundup treatments, respectively.

In addition to its effects on kikuyugrass, other exotic grasses (sweet vernal grass, *Anthoxanthum odoratum*; velvetgrass, *Holcus lanatus*; and paspalum grass, *Paspalum dilatatum*) were highly sensitive to glyphosate and did not regenerate, whereas St. Augustine grass (*Stenotaphrum secundatum*) survived even the 6% Roundup treatment and established new growth after 6 months. Other exotic species which were not readily controlled by glyphosate and which likewise proliferated in the absence of kikuyugrass included honohono "grass" (*Commelina diffusa*) and yellow ginger (*Hedychium flavescens*). Although tritonia

(Tritonia crocosmiflora) was controlled by glyphosate in higher concentrations (4 and 6% Roundup), this species was one of the most prominent exotic recolonizers of treated plots.

Native plants associated with kikuyugrass in the treatment area included shrubs, trees, and large ferns. Some of these occur only in limited areas of Hawaii, whereas others are more widely distributed in other localities as well. Sensitivity to glyphosate among many of these species depended in part on the extent to which the foliage was contacted by the spray. Thus, small plants of tree 'ohelo (Vaccinium calycinum), 'ohi'a-lehua, and 'ama'uma'u (Sadleria cyatheoides) whose foliage was closely associated with the kikuyugrass were killed or severely damaged, whereas foliage of larger plants of these species escaped direct spray contact and the plants exhibited little or no effect. The native isachne grass (Isachne distichophylla) which was rare in the study area and was treated only with 0.3% Roundup, initially appeared extremely sensitive; however, some regeneration of this species was observed after 6 months. Another native species, deschampsia grass (Deschampsia australis), exhibited less sensitivity than did kikuyugrass at comparable herbicide concentrations. Sensitivities of other native species to glyphosate are listed in Table 1.

Although the sensitivities of native plants to glyphosate varied considerably, most of these species survived the treatment and often proliferated and regenerated new growth after 6 months. Notable among these, in addition to the larger trees, shrubs, and ferns mentioned above, were small plants of 'ohi'a-lehua and the low or creeping herbaceous species wawae'iole (Lycopodium cernuum), kukae-nene (Coprosma ernodeoides), Kilauea hedyotis (Hedyotis centranthoides), and pa'iniu (Astelia menziesiana). Some of these native species survived even the 6% Roundup treatment (although with little or no new growth among the herbaceous forms). These plants, together with the exotics St. Augustine grass, tritonia, and young shoots of yellow ginger, dominated the sparse vegetation in these plots after 6 months. Other native species such as cyperus (Cyperus polystachyus) which were sensitive to glyphosate and which showed little tendency to regenerate are widely distributed in the tropics and would not be threatened by efforts to control kikuyugrass in Hawaiian NPS areas.

In addition to the 10-week and the 6 month evaluations of the plots, a long-term observation was made 27 months following treatment. During this period, the area in which some of the plots were located had been subjected to an overall treatment reportedly with about 1% Roundup as part of a general kikuyugrass eradication effort undertaken by park management. Thus, the 27-month evaluation reflected the results of a secondary treatment, applied approximately 8 months following the initial application, whereas the remaining plots had received only the initial treatment.

The plots receiving two treatments included some of those originally treated with 1 to 6% Roundup. Plots treated initially with less than 0.5% Roundup showed minimal kikuyugrass control. These areas were overgrown with healthy-appearing kikuyugrass after 27 months. Plots which were treated with greater than 0.5% Roundup continued to show substantial control with mats of dead kikuyugrass still covering the ground. Numbers of deaths among endemic and indigenous species also appeared to have increased at herbicide dilutions greater than 1%.

No apparent differences in kikuyugrass control were noted among plots to which only an original treatment of at least 0.5% Roundup was applied and those receiving a secondary 1% treatment. Both sets of plots showed 0 to 10% cover of kikuyugrass, depending on the herbicide concentration of the original treatment. This cover resulted either from reestablishment of new individuals or from escapes. A tendency for kikuyugrass to reinvade from the margins was also noted among those plots which were still separated from one another by buffer zones of untreated vegetation, whereas little healthy kikuyugrass was present in the entire region which had been generally treated a second time. This illustrates the relative efficiency of a widescale treatment program in which all kikuyugrass in a large area is treated at once, thereby preventing reinvasion of cleared areas from adjacent untreated zones.

Aside from kikuyugrass, new individuals of several species had become established within the treated plots after 27 months. Seedlings and sporelings of major recolonizing native plants included kilau (Pteridium aquilinum), kukae-nene, wawae'iole, cyperus, and Kilauea hedyotis. Other newly established natives included 'ama'uma'u, 'ohelo (Vaccinium reticulatum), tree 'ohelo, 'ohi'a-lehua, kupaoa (Dubautia scabra), isachne grass, and kolea-lau-nui (Myrsine lessertiana). Broomsedge (Andropogon virginicus), velvetgrass, and paspalum grass were the major recolonizing exotic grasses. Tritonia, prickly Florida blackberry known locally as Rubus penetrans), thimbleberry (R. rosaefolius), and ginger were also abundantly established exotics. Other newly established individuals of exotic species occurring less frequently included ironweed (Vernonia cinerea), Hypericum degeneri, honohono "grass", Japanese anemone (Anemone japonica), butterfly bush (Buddleja asiatica), strawberry guava (Psidium cattleianum), hairy cat's ear (Hypochoeris radicata), Carolina geranium (Geranium carolinianum), and European strawberry (Fragaria vesca).

SUMMARY AND MANAGEMENT IMPLICATIONS

These tests demonstrate that glyphosate may be effective in controlling kikuyugrass in and around Hawaiian forests managed as native ecosystems. This chemical may be applied in concentrations and amounts which will allow selectivity between kikuyugrass and most species of native plants associated with this exotic grass, provided that care is taken to avoid undue

exposure of natives to the herbicide. This study, which was designed to evaluate the effects of single glyphosate applications, indicates that Roundup concentrations of 0.5 to 1% (5 to 10 ml per liter of water or about 1 1/4 to 2 1/2 tablespoons per gallon) are the most effective for kikuyugrass control while causing the least damage to the majority of associated native plants. Some damage to natives may still be expected, however.

Application should be as uniform as possible, with sufficient spray pressure that the droplets are evenly dispersed and cover the target vegetation to a pre-runoff stage. Enough time should elapse between application and rainfall that the herbicide solution is no longer evident on sprayed leaves. If heavy rain falls shortly following application, retreatment may be necessary. Galvanized metal containers should not be used for Roundup solutions and care should be taken that the water used for making solutions be clean and free from soil. Mud or other impurities in the water may decrease the activity of this herbicide and therefore cause it to be less effective. As with other pesticides, all other precautions and instructions on the container label should be understood and complied with.

Treated areas should be monitored as the application results become visible and patches of kikuyugrass which may have escaped the initial spray should be treated to prevent rapid reinvasion of cleared areas. Although a single, thorough application with at least 0.5% Roundup is effective in limiting kikuyugrass, other treatment procedures, such as two or more applications Roundup in low concentrations at intervals of several weeks may also be satisfactory and aid in allowing more complete coverage. However, Romero and Mejia (1976) in Colombia reported that "split" applications of glyphosate (that is, dividing the desired dosage between two applications at a 2-week interval) were less effective in kikuyugrass control than were single applications of a given amount. Careful treatment to avoid undue spray exposure to native plant foliage may provide a significant selective advantage for these species in maintaining the integrity of the native vegetation in the treatment area.

The results of this study indicate, however, that elimination of an exotic species such as kikuyugrass which had formerly dominated an area may encourage rapid invasion of other native and exotic species. Some of these exotics, such as tritonia and St. Augustine grass, may be difficult to control with glyphosate. Other approaches, therefore, either through the use of alternate herbicides or cultural practices, such as mechanical removal of aggressive exotics, may have to be relied on until the integrity of these cleared areas can be reestablished with desirable native species.

ACKNOWLEDGEMENTS

We acknowledge the valuable help of Lani Stemmermann in plant identification, and the cooperation of the Hawaii Volcanoes National Park Resources Management Division in this study. We also thank the Regional Chief Scientist and his staff, the Research Scientist at HAVO and his staff, and Univeristy of Hawaii personnel for their manuscript reviews and helpful support.

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Table 1. Percent mortality of kikuyugrass (Pennisetum clandestinum) and associated native and nonnative vascular plants to various concentrations of Roundup 10 weeks following treatment in Hawaii Volcanoes National Park

Species	Common name	Exotic or native	% Roundup solution							
			0.05	0.1	0.3	0.5	1.0	2.0	4.0	6.0
Pennisetum clandestinum	Kikuyugrass	e	<50[1,2]	<50	<95	>95	>95	>95	>95	>95
Other grasses										
Andropogon virginicus	Broomsedge	e	--	--	--	--	--	--	>95	--
Anthoxanthum odoratum	Sweet vernal grass	e	>95	--	--	--	--	--	--	--
Deschampsia australis	Deschampsia grass	n	<10	<10	--	<75	--	--	--	--
Holcus lanatus	Velvetgrass	e	>95	>95	>95	>95	>95	>95	>95	>95
Isachne distichophylla	Isachne grass	n	--	--	>95	--	--	--	--	--
Paspalum dilatatum	Paspalum grass	e	--	--	>95	--	>95	>95	--	--
Stenotaphrum secundatum	St. Augustine grass	e	--	<10	<10	<50	<50	<50	--	<50

Other monocots										
Arundina bambusaefolia	Bamboo orchid	e	--	--	--	--	--	--	<95	--
Astelia menziesiana	Pa'iniu	n	<10	<10	<10	--	<10	--	--	--
Commelina diffusa	Honohono "grass"	e	<10	<10	<10	<25	<50	--	--	<50
Cyperus polystachyus	Cyperus	n	<10	<50	<95	>95	>95	>95	>95	--
Hedychium flavescens	Yellow ginger	e	--	<10	--	<10	--	<10	<10	--
Machaerina angustifolia	'Uki	n	<10	--	<10	--	--	--	--	--
Phaius tankervilliae	Chinese orchid	e	--	--	--	--	--	--	>95	--
Tritonia crocosmiflora	Tritonia	e	<10	<10	<25	<25	<75	<75	<95	>95
Dicots										
Coprosma ernodeoides	Kukae-nene	n	<10	<10	<50	<50	<50	<50	<75	<75
Coprosma rhynchocarpa	Pilo	n	--	--	--	<10	<10	--	--	--
Dubautia scabra	Kupaoa	n	--	--	--	--	--	>95	--	--
Hedyotis centranthoides	Kilauea hedyotis	n	--	--	<10	<10	<10	--	<10	<10
Hypochoeris radicata	Hairy cat's ear	e	--	--	--	--	<10	--	--	--
Metrosideros collina subsp. *polymorpha*	'Ohi'a-lehua (1)[3]	n	<10	<10	--	<10	<10	<10	<10	<10

Metrosideros collina subsp. *polymorpha*	'Ohi'a-lehua (s)[4]	n	<10	<10	--	<10	<10	<10	<25	<25
Myrsine lessertiana	Kolea-lau-nui	n	--	<10	--	--	--	--	--	--
Psidium cattleianum	Strawberry guava	e	--	--	--	--	--	--	--	>95
Styphelia tameiameiae	Pukiawe	n	--	--	--	--	<10	--	--	<10
Vaccinium calycinum	Tree 'ohelo (l)	n	<10	<10	<10	--	<75	<10	<25	<25
Vaccinium calycinum	Tree 'ohelo (s)	n	--	--	--	<25	<75	<95	<95	--
Vaccinium reticulatum	'Ohelo	n	--	--	--	<75	<95	--	--	<95
Ferns and fern allies										
Cibotium glaucum	Hapu'u	n	<10	--	--	--	--	--	--	--
Elaphoglossum hiratum	'Ekaha	n	--	--	<25	--	--	-	--	--
Lycopodium cernuum	Wawae'iole	n	--	<10	<10	<50	<95	<50	<50	<75
Pteridium aquilinum	Kilau	n	<50	<50	--	--	<95	>95	>95	--
Sadleria cyatheoides	'Ama'uma'u	n	<10	<10	<10	<10	--	<10	--	<75

[1]Less than 50% mortality but greater than 25% according to the following categories: <10, 10-25, 26-50, 51-75, 76-95, and >95% mortality.

[2]Kikuyugrass data derived from three replications. F-test significant at the 0.5% level.

[3]One meter tall or taller.

[4]Less than 1 meter tall.