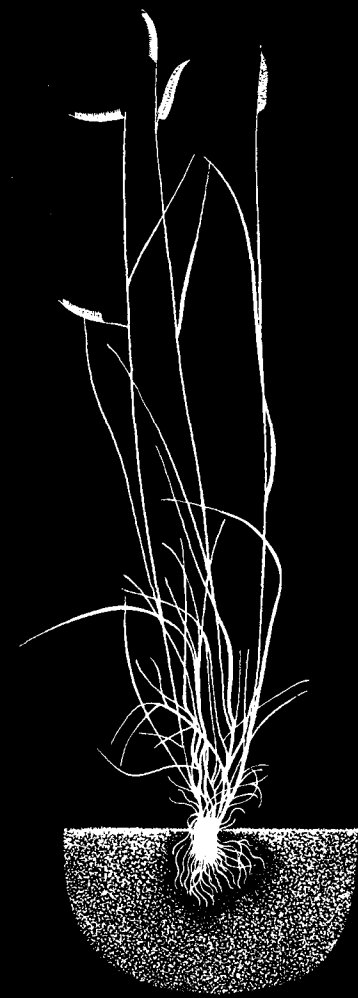
Evaluation of Soil-applied Herbicides for Vegetation Control



A Water Resources Technical Publication

RESEARCH REPORT NO. 22

United States Department of the

INTERIOR

Bureau of Reclamation

Research Report No. 22 • A WATER RESOURCES TECHNICAL PUBLICATION

Evaluation of Soil-applied Herbicides for Vegetation Control

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UNITED STATES DEPARTMENT OF THE INTERIOR
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UNITED STATES GOVERNMENT PRINTING OFFICE

WASHINGTON : 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, or the Chief Engineer, Bureau of Reclamation, Attention 841, Denver Federal Center, Denver, Colo. 80225. Price 45 cents.

Preface

This research report is offered for use by the operation and maintenance staffs of the Bureau of Reclamation, irrigation and water districts, power distribution organizations, highway maintenance organizations, universities, engineering and biological consultants, herbicide manufacturers, and others having an interest in the total control of vegetation in noncrop situations.

Complete vegetation control is desirable and often a necessary requirement on power switchyards, transmission line and tower sites, parking and equipment storage lots, irrigation structures, canal and road rights-of-way, and similar areas where vegetation produces hazards or interferes with operational procedures. In these situations, the application of soil-applied herbicides for control of higher plant growth does not produce significant environmental hazards because of the small land areas treated, soil fixation characteristics of the chemicals, and careful methods used in herbicide placement.

Weed control constitutes a major portion of annual operation and maintenance budgets. The use of soil-sterilant herbicides to produce long-term vegetation control can be a large segment of a weed control expense, especially of projects concerned primarily with power distribution. The development and subsequent use of more efficient herbicidal materials, with resulting increases in longevity of effectiveness, reduces these maintenance costs. This was the primary objective in conducting the study reported herein.

Since 1946, scientists in the Bureau of Reclamation's Division of Research in Denver, Colo., have conducted and coordinated research of various weed control problems associated with multiple-use water projects, including aquatic weeds, canal ditchbank weeds, and more recently with terrestrial noncrop vegetation control discussed in this report. These research activities are conducted cooperatively with Bureau of Reclamation regional offices and the Crops Research Division, Agricultural Research Service (ARS), of the Department of Agriculture.

The author acknowledges the assistance of Victor Miyhara, Agricultural Research Technician of the Agricultural Research Service, assigned to the Biological Investigations Section in conducting the studies; William Batts for the photography; the herbicide manufacturers who supplied many of the herbicides for evaluation tests; and all regional and project personnel of the Bureau of Reclamation and cooperative independent projects who provided statistical information on the use of soil-sterilant herbicides within their areas of operation.

Included in this publication is an informative abstract and list of descriptors, or key words, and "identifiers." The abstract was prepared as part of the Bureau of Reclamation's program of indexing and retrieving the literature of water resources development. The descriptors were selected from the "Thesaurus of Descriptors," which is the Bureau's standard for listing of key words.

Other recently published Water Resources Technical Publications of the Bureau are listed on the inside back cover of this report.

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INTRODUCTION

The use of soil-sterilant-type herbicides by the Bureau of Reclamation is widespread and varied. Because of the development in recent years of many new and possibly unproven herbicides, the selection of the most suitable materials has become increasingly difficult for Bureau field personnel. Although there is information available in the literature (*1, 2, 3, 4, 5, 6,* and *7*) * and from manufacturer's recommendations on the use of certain soil-sterilants, many times these data have not met the Bureau of Reclamation's specific requirements and needs. The present study was conducted under field conditions to evaluate some of these recommendations and to compare the performance of newer compounds and formulations with those used by the Bureau in past years.

This study was designed as a herbicide demonstration to provide information on the types of compounds and rates of application of nonselective herbicides most suitable for use by the Bureau of Reclamation to give long-term vegetation control on parking lots, power switchyards, transmission line and tower sites, irrigation canal rights-of-way, and similar areas where vegetation produces hazards or is objectionable to operational procedures.

Twenty-two herbicide formulations were evaluated for their ability to provide long-term control of shortgrass plains vegetation in an arid area from 1963 through 1967. The progress of these studies was reported in annual laboratory reports (*8*). Five additional formulations, more recently marketed, were evaluated in 1968 and 1969. Two of these products contained the basic herbicidal compounds evaluated in the first 5-year study.

Additional field evaluations of some of the newer and more promising herbicides have been made by project personnel in other geographical localities within operational areas of the Bureau of Reclamation. A Bureau-wide survey of soil-sterilant herbicide use for project maintenance was conducted in 1967 to obtain a general concept of the effectiveness of these newer materials and to obtain statistical information on the use of soil-applied herbicides by this agency. A summary of these data is included as an appendix with the thought that it would be of interest to all Bureau maintenance personnel responsible for weed control functions, and perhaps others.

* Numbers in parentheses refer to literature cited at the end of the report.

MATERIALS AND METHODS

In the first study, 22 herbicide formulations were evaluated on field test plots within the Denver Federal Center, Denver, Colo. Two of the materials included in these tests contained the same active ingredient and differed only in formulation. The bulk of the candidate herbicides was placed under test in the fall of 1962 and a few in the spring of 1963. Some materials were also applied in 1964 and 1965.

The second series of herbicide evaluations was conducted at the Bureau of Reclamation's Aquatic Weed Field Test Station, about 7 miles west of Berthoud, Colo.

Most of the herbicides used in the study are or were commercially available at the time of application, and only a few were not widely used as soil-sterilant herbicides. Certain of the materials have since been discontinued or formulations have been changed by the manufacturers.

The compounds that were evaluated are listed in table 1 according to chemical nomenclature, formulation, and common name. A laboratory identification number was assigned to each herbicide for convenience in text discussions.

Table 1.—IDENTIFICATION AND COMPOSITION OF SOIL-APPLIED HERBICIDES

Herbicide No.	Common name or abbreviated designation [1]	Chemical name and percent active ingredient	Formulation
1	monuron	3- (p-chlorophenyl) 1,1-dimethylurea, 80.0 percent	Wettable powder.
2	diuron	3- (3,4-dichlorophenyl) -1,1-dimethylurea, 80.0 percent	Do.
3	fenuron	3-phenyl-1,1-dimethylurea, 25.0 percent	Pelleted.
4	isocil [2]	5-bromo-3-isopropyl-6-methyluracil, 80.0 percent	Wettable powder.
5	BMM	Disodium tetraborate pentahydrate, 63.2 percent Disodium tetraborate decahydrate, 30.8 percent 3- (p-chlorophenyl) 1,1-dimethylurea, 4.0 percent	Granular.
6	BMM (2, 3, 6–TBA)	Disodium tetraborate pentahydrate, 80.4 percent Disodium tetraborate decahydrate, 13.1 percent 3- (p-chlorophenyl) 1,1-dimethylurea, 3.0 percent 2,3,6 trichlorobenzoic acid, 1.0 percent	Do.
7	CBM	Disodium octaborate, 73.0 percent Sodium chlorate, 25.0 percent (B_2O_3 equivalent, 49.0 percent)	Crystal.
8	Anhydrous borax	Anhydrous borax, 91.0 percent (B_2O_3 equivalent, 63.0 percent)	Do.
9	BM (2, 3, 6–TBA)	Disodium tetraborate pentahydrate, 54.5 percent Disodium tetraborate decahydrate, 35.5 percent (B_2O_3 equivalent, 39.0 percent) 2,3,6 trichlorobenzoic acid, 8.0 percent	Granular.
10	CBMM	Sodium chlorate, 40.0 percent Sodium metaborate, 57.0 percent 3- (p-chlorophenyl) 1,1-dimethylurea, 1.0 percent	Crystal.
11	monuron TCA	3- (p-chlorophenyl) 1,1-dimethylurea trichloroacetate, 22.0 percent	Granular.
12	fenuron TCA	3-phenyl-1,1-dimethylurea trichloroacetate, 22.0 percent	Pelleted.
13	simazine [3]	2-chloro-4,6,bis (ethylamino) -s-triazine, 50.0 percent (available now as 80.0 percent)	Wettable powder.
14	atrazine	2-chloro-4-ethylamino-6-isopropylamino-s-triazine, 80.0 percent	Do.
15	prometone [3]	2-methoxy-4,6,bis (isopropylamino-s-triazine, 8.0 percent, on $(NH_4)_2SO_4$ crystals (available now as Herbicide No. 26)	Granular.

Herbicide No.	Common name or abbreviated designation [1]	Chemical name and percent active ingredient	Formulation
16	prometone	2-methoxy-4,6,bis (isopropylamino-s-triazine, 2 pounds per gallon (239.7 grams/liter)	Liquid.
17	CBM	Sodium metaborate tetrahydrate, (239.7 grams/liter), 68.0 percent	Granular.
18	picloram [4]	Potassium salt of 4-amino-3,5,6,trichloropicolinic acid, 10.0 percent	Do.
19	picloram [4]	Potassium salt of 4-amino-3,5,6,trichloropicolinic acid, 2 pounds per gallon (239.7 grams/liter)	Liquid.
20	CBDM [5]	Sodium chlorate, 30.0 percent Sodium metaborate tetrahydrate, 66.5 percent (B_2O_3 equivalent, 22.7 percent) 3- (3,4-dichlorophenyl) -1,1-dimethylurea, 1.25 percent	Granular.
21	[5]	2,3,6,trichlorobenzyloxypropanol, 21.3 percent 2-ethylhexylester of 2,4-dichlorophenoxy-acetic acid, 3.12 percent 5-bromo-3-sec-butyl-6-methyluracil, 10.37 percent Total formulation, 3.2 pounds per gallon (383.5 grams/liter)	Liquid.
22	ametryne [4]	2-ethylamino-4-isopropylamino-6-methylmercapto-s-triazine, 80.0 percent	Wettable powder.
23	bromacil CBM	5-bromo-3-sec-butyl-6-methyluracil, 4.0 percent Sodium metaborate tetrahydrate, 64.0 percent (B_2O_3 equivalent, 21.8 percent) Sodium chlorate, 30.0 percent	Granular.
24	bromacil BM	5-bromo-3-sec-butyl-6-methyluracil, 4.0 percent Disodium tetraborate pentahydrate, 71.2 percent Disodium tetraborate pentahydrate decahydrate (B_2O_3 equivalent, 42.1 percent)	Do.
25	bromacil	5-bromo-3-sec-butyl-6-methyluracil, 80.0 percent	Wettable.
26	prometone CBM	2-methoxy-4,6,bis (isopropylamino) -s-triazine, 5.0 percent Sodium chlorate, 40.0 percent Sodium metaborate, 50.0 percent	Pelleted.
27	atrazine CBM	2-chloro-4-ethylamino-6-isopropylamino-s-triazine and related atrazine compounds, 8.0 percent Sodium chlorate, 40.0 percent Sodium metaborate, 47.0 percent	Do.

[1] Common names of combinations accepted by the Terminology Committee of the Weed Society of America (*9*).
[2] Herbicide discontinued by the manufacturer; substitute bromacil, Herbicide No. 25.
[3] Herbicides no longer commercially available with this specific formulation. Changes in respective herbicides are indicated.
[4] Herbicide was considered experimental at the time of application or not widely used for total vegetation control.
[5] Herbicides that have been discontinued by the manufacturer.

The herbicides listed in table 1 were evaluated by application on vegetation-covered plots 1 square rod (25,269 square meters) in area. Each plot is bordered on all sides with an undisturbed check area ½ rod (2.514 meters) in width. All herbicides were applied at three rates each on the replicated 1-square-rod test plots.

Rates of herbicide application are based on the commonly used treatment designation of pounds per acre of total formulation. Conversions for the pound-per-acre rate to pounds per 100 square feet and corresponding metric values are given in table 11. Plot locations were randomized according to standard statistical methods. Selection of the width of the border strip surrounding each test plot was ½ rod because of limited available space. The check areas proved to be sufficiently wide to buffer effects of herbicidal cross contamination, and the large vegetated area surrounding the test site provided an adequate source of plant propagules for reinvasion of treated plots. The field test area located within the grounds of the Denver Federal Center was approximately 2½ acres (1.01 hectares), and the Aquatic Weed Field Station test area was approximately 1/10 acre (0.04 hectare). A limited test was also conducted at the Aquatic Weed Test Station site comparing the effectiveness of granular and wettable powder formulations of atrazine (applied at the same rates of active atrazine) to gravel-covered soil and to soil alone. These plots were reduced to

16 square feet (1.49 square meters) to economize on the amount of gravel required. The gravel plots, approximately 4 inches (10.16 cm) in thickness, were composed of ½- to 1½-inch-size aggregates. The herbicides were applied after gravel placement to correspond to treatment of aggregate-covered power switchyards and storage areas under normal operational conditions.

In selecting rates of herbicide application in the 1963–67 studies, the median rate of application was chosen to correspond similarly to manufacturers' recommendations for complete vegetation control of herbaceous terrestrial weeds, under climatic conditions and vegetation type existing at the test area. Low herbicide concentrations were based on minimum rates expected to provide some nonselective vegetation control. These concentrations ranged from one-fourth to four-fifths of the normal recommended rates. These low rates of application were used to produce information on the minimum rate at which a herbicide may be expected to perform satisfactorily. High-rate applications were made primarily to ascertain the potential of extending the effective longevity of any one herbicide treatment, therefore eliminating need for retreatments for long periods. The high application rates were selected on a basis of maximum practical rates, which ranged from 1⅓ to 2 times greater than the median rate of herbicide application. The 1968–69 tests were limited to two rates of herbicide application. The high rate corresponded roughly to the median rate of application recommended by the manufacturers. The other rate of application was empirical but was somewhat less than lower rates recommended by manufacturers. All of these rates were based on the content of organic formulation and not the total formulation which in the case of granular materials contained active inorganic components.

The rates of application, date of application, and methods used to make treatments of each herbicide formulation are given in table 2.

Table 2.—APPLICATION RATES OF HERBICIDES EVALUATED FOR COMPLETE VEGETATION CONTROL

Herbicide No.	Common name or abbreviated designation	Rates of application (2 replications/rate)		Dates of application	Application methods
		Lb/acre active ingredient	Lb/acre total formulation		
1	monuron	64.0	80	10–11–62	Wettable powder applied with 3 gallons of water per plot, using a garden sprinkler can.
		32.0	40		
		16.0	20		
2	diuron	64.0	80	10–17–62	Do.
		32.0	40		
		16.0	20		
3	fenuron	20.0	80	10–17–62	Granules applied with a rotating vane-type herbicide applicator.
		12.5	50		
		7.5	30		
4	isocil	16.0	20	10–17–62	Wettable powder applied with 3 gallons of water per plot, using a garden sprinkler can.
		12.0	15		
		8.0	10		
5	BMM	784.0	800	10– 9–62	Granules applied with a rotating vane-type herbicide applicator.
		392.0	400		
		196.0	200		
6	BMM (2,3,6–TBA)	780.0	800	10– 9–62	Do.
		390.0	400		
		195.0	200		
7	CBM	1,568.0	1,600	10–11–62	Crystals applied with a turf-type fertilizer spreader, plots sprinkled with 2 gallons of water following application.
		784.0	800		
		392.0	400		
8	Anhydrous borax	3,185.0	3,500	10–11–62	Crystals applied with a turf-type fertilizer spreader, plots sprinkled with 3 gallons of water following application.
		1,820.0	2,000		
		1,365.0	1,500		
9	BM (2,3,6–TBA)	235.2	240	10–10–62	Granules applied with a rotating vane-type herbicide applicator.
		176.4	180		
		117.6	120		

Herbicide No.	Common name or abbreviated designation	Rates of application (2 replications/rate)		Dates of application	Application methods
		Lb/acre active ingredient	Lb/acre total formulation		
10	CBMM	1,274.0	1,300	10–10–62	Crystals applied with a turf-type fertilizer spreader, plots sprinkled with 3 gallons of water following application.
		784.0	800		
		392.0	400		
11	monuron TCA	66.0	300	10–10–62	Granules applied with a rotating vane-type herbicide applicator.
		44.0	200		
		22.0	100		
12	fenuron TCA	26.4	120	10–10–62	Pellets applied with a rotating vane-type herbicide applicator.
		17.6	80		
		13.2	60		
13	simazine	15.0	30	10–11–62	Wettable powder applied with 3 gallons of water per plot, using a garden sprinkler can.
		10.0	20		
		7.5	15		
14	atrazine	12.0	15	10–11–62	Do.
		8.0	10		
		6.4	8		
15	prometone	30.0	375	4–16–63	Granules applied with a rotating vane-type herbicide applicator.
		15.0	187.5		
		8.0	100		
16	prometone	30.0	120	4–16–63	Liquid applied with 3 gallons of water per plot, using a garden sprinkler can.
		15.0	60		
		8.0	32		
17	CBM	1,960.0	2,000	4–16–63	Granules applied with a rotating vane-type herbicide applicator.
		980.0	1,000		
		588.0	600		
18	picloram	4.0	40	4–16–63	Do.
		2.0	20		
		0.5	5		
19	picloram	4.0	16	4–16–63	Liquid applied with 3 gallons of water per plot, using a garden sprinkler can.
		2.0	8		
		0.5	2		
20	CBDM	1,759.5	1,800	4–10–64	Granules applied with a rotating vane-type herbicide applicator.
		879.8	900		
		488.8	500		
21	.....	25.6	73.47 (8 gallons)	3–31–65	Liquid applied with 2 gallons of water per plot, using a garden sprinkler can.
		12.8	36.74 (4 gallons)		
		6.4	18.37 (2 gallons)		
22	ametryne	16.0	20	3–31–65	Wettable powder applied with 3 gallons of water per plot, using a garden sprinkler can.
		8.0	10		
		4.0	5		
23	bromacil CBM	3.0 (as bromacil)	75	11– 8–67	Granules applied with a rotating vane-type herbicide applicator.
		8.0 (as bromacil)	200		
24	bromacil BM	3.0 (as bromacil)	75	11– 8–67	Do.
		8.0 (as bromacil)	200		
25	bromacil	4.0	5	11– 8–67	Wettable powder applied with 3 gallons of water per plot, using a garden sprinkler can.
		12.0	15		

Herbicide No.	Common name or abbreviated designation	Rates of application (2 replications/rate)		Dates of application	Application methods
		Lb/acre active ingredient	Lb/acre total formulation		
26	prometone CBM	5.0 (as prometone)	100	11– 8–67	Pellets applied with a rotating vane-type herbicide applicator.
		15.0 (as prometone)	300		
27	atrazine CBM	6.0 (as atrazine)	75	11– 8–67	Do.
		16.0 (as atrazine)	200		
	Comparison of herbicide application to gravel-covered areas versus soil and wettable powder versus granular formulation on 4-square-foot plots				
27	atrazine CBM	12.0 (as atrazine)	150 soil	11– 8–67	Pellets applied by hand.
		12.0 (as atrazine)	150 gravel		
14	atrazine	12.0 (as atrazine)	15 soil	11– 8–67	Wettable powder applied with ½ gallon of water per plot, using a garden sprinkler can.
		12.0 (as atrazine)	15 gravel		

Plant growth at both test sites is a mixture of high plains grass and some foothills herbaceous species with representations of disturbed area vegetation. Only a few low-form woody plants are found in the immediate areas. Ecologically, the areas might be classified as a disclimax of short grass plains grading into a foothills transition zone. Figure 1 illustrates the general vegetative cover of both study sites.

The test plots at the Denver Federal Center were located on a gentle slope with a general southeast exposure. Potential drainage and runoff problems were considered in establishment of the plot locations. These factors did not cause discernible difficulties to the study. The Aquatic Weed Test Station plots were on a level area.

Soil in the Federal Center test plot area is a mixture of well-developed heavy alluvial clays mixed with gravels. These soils are alluvium from the Denver formation and would fall in a classification of Denver or Colona types as defined by the Soil Conservation Service of the U.S. Department of Agriculture (*10*). Soil at the Aquatic Weed Test Station plot area is a reasonably heavy alluvial clay grading into loam. This soil is shallow overlaying sandstone-limestone formations found in eastern hog-back areas of the Rocky Mountains. Classification of these soils was not obtained.

Plant species collected from the test areas and identified according to standard taxonomic publications (*11*) (*12*) are listed in table 3.

Table 3.—IDENTIFICATION OF PLANT SPECIES OCCURRING ON THE HERBICIDE TEST SITES

Genus and Species	*Common Name* [1]
**Agropyron cristatum* L.	crested wheatgrass
**Agropyron smithii* Rydb.	western wheatgrass
**Amaranthus graecizans* L.	prostrate pigweed
**Ambrosia trifida* L.	giant ragweed
**Argemone intermedia* Sweet	bluestem pricklepoppy
Aristida adscensionis L.	(6 weeks threeawn)
Artemisia dracunculoides L.	(sagebrush)
Asclepias latifolia (Torr.) Raf	broadleaf milkweed
Aster foliaceus L.	
Atriplex argentea Nutt.	silverscale saltbush
**Bouteloua oligostachya* (Nutt.) Torr.	(blue grama)
**Bromus tectorum* L.	downy brome
**Buchloe dactyloides* (Nutt.)	buffalograss
Chenopodium album L.	common lambsquarters
Chrysothamnus pulchellus (A. Gray) Greene	southwest rabbitbrush
Cirsium arvense (L.) Scop.	Canada thistle
Comandra pallida Nutt.	(bastard toadflax)
Convolvulus arvensis L.	field bindweed
Descurainia sophia (L.) Webb	flixweed
Epilobium spp. L.	(willow herb)
Erigeron canus L.	(daisy)

Genus and Species	*Common Name* [1]
Euphorbia albomarginata Torr. and Gray	whitemargin spurge
**Helianthus annus* L.	sunflower
**Kochia scoparia* (L.) Roth	kochia
Laciniaria punctata Hill	(blazing star)
**Lactuca scariola* L.	prickly lettuce
Lithospermum linearifolium L.	
**Lygodesmia juncea* (Pursh) D. Don	skeletonweed
**Malvastrum coccineum* Gray	(false mallow)
Medicago sativa L.	alfalfa
Mertensia pratensis Roth	(forget-me-not)
**Opuntio* spp.	prickly pear cactus
Oxytropis lambertii Pursh	Lambert crazy weed
Panicum capillare L.	witchgrass
Pentstemon harbouri	(beard-tongue)
Physalis longifolia Nutt.	longleaf groundcherry
**Psoralea tenuiflora* L.	(scurf pea)
Ratibida columnifera Woot and Standl.	prairie coneflower
**Rumex* spp. L.	(sorrel dock)
**Salsola kali* L .Var. tenuifolia Tausch	Russian thistle
Senecio cernuus L.	(groundsel)
S. douglasi L.	(groundsel)
Silphium perfoliatum L.	cupplant
Solidago lanceolata L.	(goldenrod)
S. missouriensis Nutt.	Missouri goldenrod
S. pumila	(goldenrod)
Taraxacum officinale Weber	dandelion
Thlaspi arvense L.	field pennycress
**Verbascum thapsus* L.	common mullein
**Verbena bracteata* Lagi and Rodr.	prostrate vervain
Vicia americana Muhl.	American vetch
Yucca glauca Nutt.	small soapweed

Additional species found only at the Aquatic Weed Field Test Station soil-applied herbicide test site (in addition to species marked with asterisk):

Agropyron intermedium (Host) Beav.	(intermediate wheatgrass)
Bromus inermis Leyss. (Var?)	(smooth brome grass)
Carduus nutans L.	musk thistle
Eragrostis spp. Host	lovegrass
Euphorbia supina Raf.	prostrate spurge

* Species occurring at Aquatic Weed Field Test Station site.

[1] Common names and authorities used correspond to those accepted by the Terminology Committee of the Weed Society of America (*13*) when listed.

Vegetation debris was not removed from any test plot prior to herbicide application because of the desire to test all materials under severe conditions. Any herbicide or formulation producing satisfactory results with a minimum of application preparation would be considered more suitable for routine use by Bureau operation and maintenance personnel. The Aquatic Weed Test Station site was mowed prior to herbicide placement.

Denver Federal Center site, October 1967.

Aquatic Weed Field Test Station site, October 1968.

Figure 1.—Soil-applied herbicide test areas.

RESULTS AND DISCUSSION

The effectiveness of the herbicidal treatments in controlling vegetation on each plot was observed and rated at the end of each growing season. All applications were also rated in the early summer following the application to determine rapidity of herbicidal activity or vegetation "knockdown" characteristics.

Herbicide injury ratings are observational estimates of percent vegetation control produced by the treatments. Observational estimates could be misleading in situations of less than total control. However, due to the extensive layout of the experiments and time-cost of detailed plant counts on a grid basis, this type of evaluation was not practical. The long-term gross effects were of primary importance, and slight variations that might be exhibited by a detailed injury rating system were not justified.

Percentage control ratings for each compound at a given application rate (including both replications) were statistically analyzed for significance by methods described by Snedecor (*14*) for "Students' t-distribution" of sampling. The standard error for each data group was determined, and from these statistics the 5-percent confidence limits were established. This provided information on the amount of overlap of percent vegetation control produced by each compound. The confidence limits are coded alphabetically and reported along with the arithmetical mean percent vegetation control attained by each material. The range of variability of each compound is graphically shown by the overlapping of common letters and the reduction of vegetation control as these letters progress in alphabetical order.

The overall performance of each herbicide formulation tested during the 5 years from 1963 to 1967 is listed in tables 4, 5, and 6. Materials tested during the 3 to 4 growing seasons from 1964 through 1967 are given in table 7. Data given in these tables indicate the relative standing of a herbicide as compared to other materials at any of the three rates of application.

Table 4.—SIGNIFICANT PERCENT VEGETATION CONTROL OBTAINED WITH HERBICIDES EVALUATED OVER FIVE GROWING SEASONS, 1963 THROUGH 1967—HIGH APPLICATION RATE

Herbicide No.	Common name or abbreviated designation	Mean percent vegetation control on duplicate plots	
2	diuron	100.0	a*
15	prometone	97.5	ab
16	prometone	95.5	ab
4	isocil	80.3	abcd
5	BMM	71.1	abcdef
1	monuron	61.0	bcdefg
14	atrazine	59.2	bcdefgh
10	CBMM	55.0	bcdefghi
11	monuron TCA	27.0	defghijk
17	CBM	26.7	efghijk
7	CBM	23.6	efghijk
9	BM (2, 3, 6-TBA)	21.8	efghijk
12	fenuron TCA	11.5	fghijk
6	BMM (2, 3, 6-TBA)	3.5	fghijk
19	picloram	10.5	ghijk
8	anhydrous borax	13.5	ijk
3	fenuron	9.0	ijk
13	simazine	2.0	ijk
18	picloram	0.0	k

*Letters in common denote that mean percent control ratings do not differ significantly at the 5-percent level.

The only materials demonstrating the best overall performance during the 5 years of testing at both the high and medium application rates were the two prometone formulations (Nos. 15 and 16) and isocil (No. 4). The long-term effectiveness of these materials is shown in figures 2, 3, and 4.

Diuron, Herbicide No. 2, produced excellent control (100 percent without variability) at the high rate through 5 years (figure 5), but was completely ineffective at the lower rates since the start of the study. This high-rate treatment was the most characteristic instance where an excess of herbicide produced satisfactory results as opposed to the complete ineffectiveness of normal or less than normal rates. This herbicide is not usually recommended for use in areas of low rainfall, due in part to the chemical's low water solubility (42 ppm). How-

Table 5.—SIGNIFICANT PERCENT VEGETATION CONTROL OBTAINED WITH HERBICIDES EVALUATED OVER FIVE GROWING SEASONS, 1963 THROUGH 1967—MEDIAN APPLICATION RATE

Herbicide No.	Common name or abbreviated designation	Mean percent vegetation control on duplicate plots	
15	prometone	89.4	abc*
4	isocil	84.9	abcd
16	prometone	65.2	bcdef
10	CBMM	36.3	defghi
11	monuron TCA	16.0	defghij
3	fenuron	22.8	efghij
14	atrazine	20.0	efghij
9	BM	19.3	efghij
17	CBM	18.6	efghij
1	monuron	20.4	fghij
7	CBM	13.1	fghij
13	simazine	12.0	fghij
6	BMM (2, 3, 6-TBA)	11.7	fghij
19	picloram	10.0	fghij
5	BMM	11.0	ghij
12	fenuron TCA	10.0	ghij
8	anhydrous borax	3.5	hij
2	diuron	1.9	ij
18	picloram	0.0	j

*Letters in common denote that mean percent control ratings do not differ significantly at the 5-percent level.

Table 6.—SIGNIFICANT PERCENT VEGETATION CONTROL OBTAINED WITH HERBICIDES EVALUATED OVER FIVE GROWING SEASONS, 1963 THROUGH 1967—LOW APPLICATION RATE

Herbicide No.	Common name or abbreviated designation	Mean percent vegetation control on duplicate plots	
16	prometone	52.0	abcdefg*
14	atrazine	44.3	bcdefgh
15	prometone	44.5	cdefg
4	isocil	38.1	cdefghi
10	CBMM	25.8	defghij
11	monuron TCA	24.2	defghij
9	BM (2, 3, 6-TBA)	18.1	defghij
1	monuron	18.9	efghij
17	CBM	16.3	efghij
12	fenuron TCA	10.5	fghij
7	CBM	5.0	ghij
2	diuron	2.5	ghij
6	BMMC 2, 3, 6-TBA	2.5	ghij
5	BMM	2.1	hij
8	anhydrous borax	2.0	hij
3	fenuron	0.5	ij
13	simazine	0.5	ij
18	picloram	0	j
19	picloram	0	j

*Letters in common denote that mean percent control ratings do not differ significantly at the 5-percent level.

ever, these data suggest that if sufficient quantities of this herbicide are applied, an effective portion can be leached into the root zone and become available to the plants over extended periods.

High-rate applications of atrazine (Herbicide No. 14) produced very good to excellent control through 3 years of exposure (figure 6), but exhibited negligible to complete loss of activity through the fourth and fifth season of testing (figure 11). Variable results were obtained at the low and median rates, ranging from very good to poor.

***Figure 2.*—Good vegetation control produced by median-rate treatment with Herbicide No. 4 (isocil) after 5 years. October 1967.**

***Figure 3.*—After five seasons' exposure, very good vegetation control was still produced by the granular formulation of prometone, Herbicide No. 15, applied at the median rate. The effects of this material moved laterally from the treated area. October 1967.**

Table 7.—SIGNIFICANT PERCENT VEGETATION CONTROL OBTAINED WITH HERBICIDES EVALUATED OVER THREE TO FOUR GROWING SEASONS, 1964 THROUGH 1967

Herbicide No.	Common name or abbreviated designation	Mean percent of control from two plot replications			
		Application rate			
		High	Median	Low	Exposure
20	CBDM	65.0 abcde*	0 e	15.0 abcde	Four growing seasons
21	—	60.0 abcde	1.0 de	0 e	Three growing seasons
22	Ametryne	0 e	0 e	0 e	Do.

*Letters in common denote that mean percent control ratings do not differ significantly at the 5-percent level when compared to other herbicides applied at the high, low, or median rates, respectively.

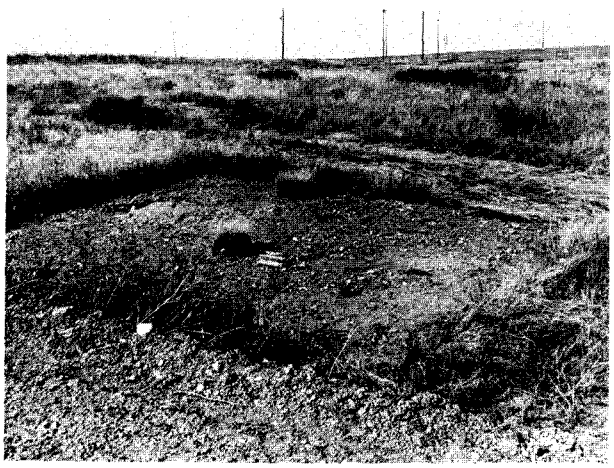

Figure 4.—Long-term control provided by a high-rate treatment with liquid prometone, Herbicide No. 16, after five seasons. The area in the immediate foreground was disturbed by construction activities just prior to the final observation. October 1967.

The overall 5-year activity of inorganic compounds was relatively low, as shown in the control ratings of tables 4 through 6. All of these materials demonstrated good vegetation control during early portions of the study, but lost effectiveness by the end of the third season, as shown in figure 7.

A few of the inorganic-organic combination herbicides such as Herbicide No. 5 (BMM), Herbicide No. 10 (CBMM) and the organic herbicide monuron (Herbicide No. 1) were producing good vegetation control through the third year of testing when applied at high rates. Figure 8 shows typical results of these types of materials after 3 years. All inorganic-organic combinations tested during the 1963 through 1967 studies were losing effectiveness by the end of the fourth season, as illustrated in figure 9.

High-rate applications of the organic combination Herbicide No. 21 exhibited fairly good control through 3 years of testing, as shown in figure 10.

Figure 5.—Five years of total plant growth control provided by a high-rate treatment with diuron, Herbicide No. 2. October 1967.

Figure 6.—Excellent vegetation control demonstrated by a high-rate application of atrazine, Herbicide No. 14, at the end of the third season of testing. October 1965.

Figure 7.—The borate-chlorate formulation of Herbicide No. 7, applied at a median rate, lost herbicidal effectiveness after 3 years' exposure. October 1965.

Figure 8.—High-rate application of the chlorate-borate-monuron combination of Herbicide No. 5 demonstrated good vegetation control through 3 years. October 1965.

Figure 9.—High-rate application of the chlorate-borate-monuron combination of Herbicide No. 10 lost effective vegetation control after 4 years. October 1966.

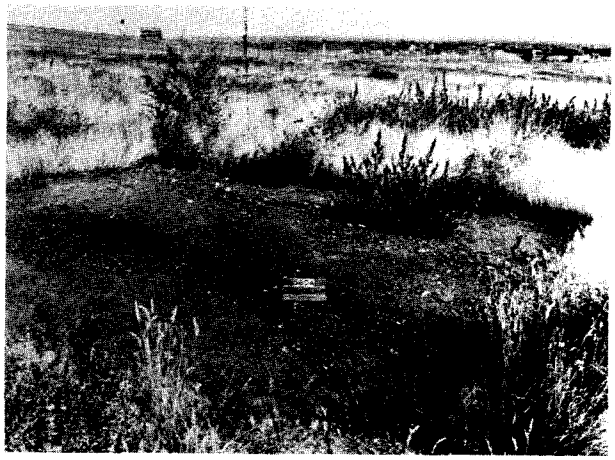

Figure 10.—Herbicide No. 21 produced good vegetation control for 3 years when applied to the plot at a high rate. October 1967.

Low-rate applications generally did not produce effective control over the first 1 or 2 years in the 1963–67 studies. The limited level of low-rate herbicidal activity is reflected in table No. 6, where only the two prometone formulations (Nos. 15 and 16), atrazine (No. 14), and isocil (No. 4) exhibited some vegetation control, which occurred mainly during the early portion of the testing. Low-rate applications did not produce detectable herbicidal activity after 5 years.

Median-rate applications of herbicides reflected somewhat better overall vegetation control than low-rate applications, excepting Herbicides Nos. 4, 15, and 16 which showed good overall activity. Most of the median-rate treatments would have required retreatment during the third through fifth years of exposure.

The results of 2 years' evaluation of five newer herbicide formulations that became available since the initial 1963–67 studies are presented in table 8.

Two of the herbicides were recently marketed as pelleted formulations of herbicides tested in 1963–67, prometone CBM (Herbicide No. 26) and atrazine CBM (Herbicide No. 27). Both of these granular materials demonstrated good to excellent vegetation control at the high rates of application as shown in figure 11, but produced inadequate activity at the low rates as shown in figure 12. Herbicide No. 25, bromacil, is a wettable powder formulation that was evaluated as a substitute for isocil, Herbicide No. 4, studied in 1963–67. Isocil has been discontinued by the manufacturer. Bromacil demonstrated herbicidal action equal to or better than isocil and would be considered as a satisfac-

Figure 11.—High-rate application of prometone CBM (Herbicide No. 26) shows good control over 2 years. October 1969.

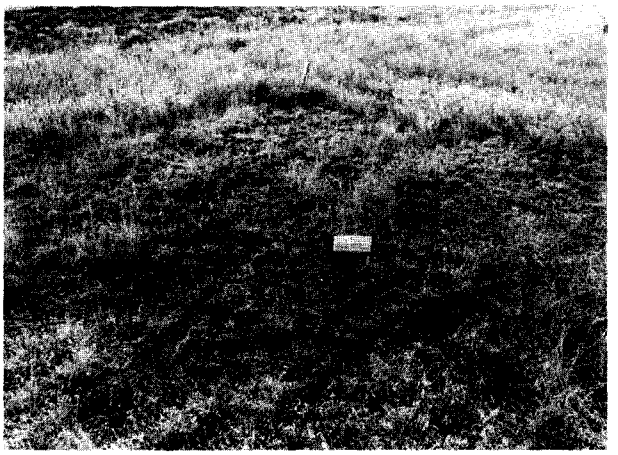

Figure 12.— Low-rate application of prometone CBM (Herbicide No. 26) produced inadequate control. October 1968.

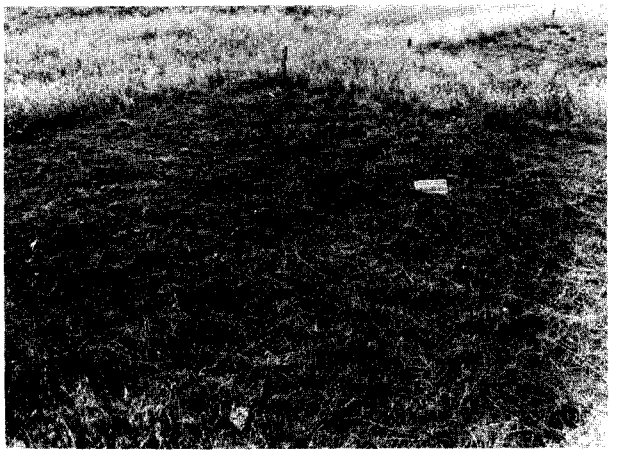

Figure 13.—Granular formulation of bromacil (Herbicide No. 24) produced good control over 2 years. October 1969.

Table 8.—SIGNIFICANT PERCENT VEGETATION CONTROL OBTAINED WITH HERBICIDES EVALUATED OVER TWO GROWING SEASONS, 1968 AND 1969—HIGH RATE

Herbicide No.	Common name or abbreviated designation	Mean percent vegetation control on duplicate plots	
26	prometone CBM	96.50	a*
23	bromacil CBM	96.25	a
25	bromacil	93.75	ab
24	bromacil BM	86.75	ab
27	atrazine CBM	67.75	abc
	LOW RATE		
25	bromacil	49.25	bcdef*
23	bromacil CBM	39.50	cdef
24	bromacil BM	32.50	cdefg
26	prometone CBM	15.25	defgh
27	atrazine CBM	10.37	efgh
	EVALUATION OF HERBICIDES APPLIED TO SOIL VERSUS GRAVEL-COVERED SOIL		
27—gravel plots	atrazine CBM	87.50	ab*
27—soil plots	atrazine CBM	78.50	ab
14—gravel plots	atrazine	77.50	abc
14—soil plots	atrazine	64.25	abcd

*Letters in common denote that mean percent control ratings do not differ significantly at the 5-percent level.

tory substitute. Two granular formulations of bromacil were represented by Herbicides Nos. 23 and 24. Both produced good vegetation control at high rates over 2 years of testing, as seen in figure 13. Bromacil CBM (Herbicide No. 23), formulated with the chlorate-borate inorganic carrier, was slightly superior to bromacil BM (Herbicide No. 24), having the borate carrier only. None of the low-rate applications were considered satisfactory, except that produced during the first year's exposure of the bromacil wettable powder formulation.

The limited study comparing the effectiveness of wettable powder and granular formulations on gravel-covered soil test plots revealed only limited differences. The granular formulation of atrazine (Herbicide No. 27) was slightly more effective than the wettable powder, Herbicide No. 14, over a 2-year exposure. Similarly, the two atrazine formulations were about equally effective when applied either to gravel-covered soil or soil plots alone, the gravel plots showing slightly greater effectiveness.

These tests suggest that soil-sterilant herbicides can be applied over gravel aggregate covered areas and still provide vegetation control equal to pretreating soil areas prior to aggregate placement. Also, it appears that granular formulations could be utilized as long as adequate post-treatment rainfall occurs on the treatment sites.

The author had an opportunity to evaluate one of the more promising herbicides on a large area. A 1¼-acre site at the Denver Federal Center was treated with the liquid formulation of prometone (Herbicide No. 16) in November 1965. This acreage was treated at a rate of 18¾ pounds per acre (active ingredient), using 100 gallons of water as diluent for power sprayer application. The area was cleaned of all vegetation debris and leveled prior to treatment. The plot is being utilized by the Concrete and Structural Branch of the Research Division for field exposure of concrete test samples. The vegetation on the area surrounding the concrete sample test site consisted of a mixture of grasses and herbaceous vegetation typical of the herbicide test site, but in addition there were a few representative deep-rooted perennial weeds such as field bindweed, scurf pea, and Canada thistle.

***Figure 14.*—Two years of excellent vegetation control was provided by a single application of prometone, Herbicide No. 16, to a concrete sample field test site on the Denver Federal Center grounds. Portions of the 1-1/4-acre site were disturbed by construction activities duing 1966 and 1967. October 1967.**

Excellent vegetation control was observed throughout the 1966 and 1967 growing seasons with little survival of deep-rooted perennials for 2 years, as shown in figure 14. A very limited amount of spot retreatment with granular prometone (Herbicide No. 26) was required in the spring of 1968 to provide total vegetation control in this area. This plant growth developed primarily because of construction disturbance of the soil in these spotted areas. In 1969 the area was still almost totally devoid of vegetation except for an occasional deep-rooted perennial and annual broadleaf plants.

A summary evaluation was made on the over-all performance of each herbicide on a year-to-year basis. The results of the evaluation of each herbicide and rate of application with a description of the annual rating system are given in table 9. A graphic representation of the mean percent vegetation control data on each herbicide is provided in figure 15.

Table 9.—YEARLY RATINGS OF PERCENT VEGETATION CONTROL AND EFFECTIVENESS OF HERBICIDES

Herbicide No.	Common name or abbreviated designation	Rate, Lb/acre ai	Overall ratings of vegetation control [1]									
			First season		Second season		Third season		Fourth season		Fifth season	
			Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating
1	monuron	64.0	76.67	Very good	77.25	Very good	50.00	Good	50.00	Good	50.00	Good
	(wettable	32.0	47.50	Fair	43.75	Fair	12.50	Poor	0.50	Very poor	1.00	Very poor
	powder)	16.0	59.00	Fair	35.00	Fair	3.00	Very poor	0.50	Very poor	0	None
2	diuron	64.0	70.83	Very good	100.00	Excellent	100.00	Excellent	100.00	Excellent	100.00	Excellent
	(wettable	32.0	2.50	Very poor	3.00	Very poor	0	None	0	None	2.00	Very poor
	powder)	16.0	10.00	Very poor	0.50	Very poor	0	None	0	None	0	None
3	fenuron	20.0	30.00	Fair	6.25	Very poor	0	None	0	None	0	None
	(pelleted)	12.5	63.00	Very good	52.50	Good	0	None	0	None	0	None
		7.5	5.83	Very poor	7.50	Very poor	0	None	0	None	0	None
4	isocil	16.0	78.83	Very good	94.75	Excellent	75.00	Very good	75.00	Very good	62.50	Very good
	(wettable	12.0	64.33	Very good	96.75	Excellent	97.50	Excellent	91.50	Excellent	42.50	Good
	powder)	8.0	64.17	Very good	86.75	Excellent	16.00	Poor	2.00	Very poor	0	None

Herbicide No.	Common name or abbreviated designation	Rate, Lb/acre ai	Overall ratings of vegetation control [1]									
			First season		Second season		Third season		Fourth season		Fifth season	
			Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating
5	BMM (granular)	784.0	68.33	Very good	98.00	Excellent	97.00	Excellent	50.00	Good	13.50	Poor
		392.0	28.67	Poor	31.25	Fair	0	None	0	None	0	None
		196.0	5.83	Very poor	3.75	Very poor	0.50	Very poor	0	None	0	None
6	BMM (2,3, 6-TBA) (granular)	780.0	66.67	Very good	62.50	Very good	50.00	Very good	5.00	Very poor	0	None
		390.0	44.17	Fair	11.25	Poor	1.00	Very poor	0	None	0	None
		195.0	9.00	Very poor	0.00	Very poor	0	None	0	None	0	None
7	CBM (crystal)	1,568.0	91.17	Excellent	54.75	Good	2.50	Very poor	0.50	Very poor	0	None
		784.0	78.00	Very good	23.00	Poor	0	None	0	None	0	None
		392.0	50.83	Fair	3.75	Very poor	0	None	0	None	0	None
8	anhydrous borax (crystal)	3,185.0	56.67	Good	6.25	Very poor	0	None	0	None	0	None
		1,820.0	45.83	Fair	12.50	Poor	0	None	0	None	0	None
		1,365.0	13.33	Very poor	1.25	Very poor	0	None	0	None	0	None
9	BM (2,3, 6-TBA) (granular)	235.2	92.83	Excellent	7.50	Very poor	0	None	0	None	0	None
		176.4	81.83	Very good	10.00	Very poor	0	None	0	None	0	None
		117.6	63.50	Very good	1.75	Very poor	0	None	0	None	0	None
10	CBMM (crystal)	1,274.0	100.00	Excellent	97.25	Excellent	77.50	Very good	3.00	Very poor	0	None
		784.0	99.00	Excellent	58.75	Very good	30.00	Very good	12.50	Poor	0	None
		392.0	88.33	Excellent	35.50	Fair	20.50	Poor	0	None	0	None
11	monuron TCA (granular)	66.0	85.00	Excellent	57.50	Very good	5.00	Very poor	0	None	0	None
		44.0	75.00	Very good	7.50	Very poor	0	None	0	None	0	None
		22.0	57.50	Good	38.00	Fair	1.00	Very poor	0	None	0	None
12	fenuron TCA (pelleted)	26.4	47.83	Fair	4.25	Very poor	0	None	0	None	0	None
		17.6	35.0	Fair	7.50	Very poor	0	None	0	None	0	None
		13.2	41.67	Fair	0.50	Very poor	0	None	0	None	0	None
13	simazine (wettable powder)	15.0	5.00	Very poor	7.50	Very poor	1.00	Very poor	0	None	0	None
		10.0	32.83	Fair	32.50	Fair	0	None	0	None	0	None
		7.5	2.00	Very poor	0.50	Very poor	0	None	0	None	0	None
14	atrazine (wettable powder)	12.0	69.00	Very good	97.75	Excellent	99.00	Excellent	13.50	Poor	0	None
		8.0	35.00	Fair	46.25	Good	10.00	Poor	0	None	0	None
		6.4	63.33	Very good	92.50	Very good	37.50	Fair	0.50	Very poor	0	None
15	prometone (granular)	30.0	88.00	Excellent	99.25	Excellent	100.00	Excellent	100.00	Excellent	95.00	Excellent
		15.0	88.25	Excellent	98.75	Excellent	99.00	Excellent	99.00	Excellent	62.50	Very good
		8.0	66.25	Good	78.00	Very good	65.00	Very good	22.50	Fair	0.	None
16	prometone (liquid)	30.0	92.50	Excellent	96.75	Excellent	99.00	Excellent	95.00	Excellent	92.50	Excellent
		15.0	75.00	Very good	88.25	Excellent	70.00	Very good	51.00	Good	50.00	Good
		8.0	62.50	Good	90.75	Excellent	94.00	Excellent	14.00	Poor	0	None
17	CBM (granular)	1,960.0	95.17	Excellent	48.75	Good	15.00	Poor	1.00	Very poor	1.00	Very poor
		980.0	86.67	Excellent	32.50	Fair	0.50	Very poor	0	None	0	None
		588.0	86.17	Excellent	20.00	Poor	0	None	0	None	0	None
18	picloram (granular)	4.0	12.51	Poor	0	None	0	None	0	None	0	None
		2.0	0	None	0	None	0	None	0	None	0	None
		0.5	1.25	Very poor	0	None	0	None	0	None	0	None
19	picloram (liquid)	4.0	35.00	Fair	3.50	Very poor	0	None	0	None	0	None
		2.0	50.00	Good	0.25	Very poor	0	None	0	None	0	None
		0.5	5.50	Very poor	0	None	0	None	0	None	0	None
20	CBDM (granular)	1,759.0	52.50	Good	82.50	Very good	62.50	Very good	65.00	Very good	-	-
		879.8	10.50	Poor	85.00	Excellent	3.00	Very poor	0	None	-	-
		488.8	3.75	Very poor	43.00	Good	15.00	Poor	15.00	Poor	-	-

Herbicide No.	Common name or abbreviated designation	Rate, Lb/acre ai	Overall ratings of vegetation control [1]									
			First season		Second season		Third season		Fourth season		Fifth season	
			Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating	Mean percent control	Rating
21	.....	25.6	99.50	Excellent	92.00	Excellent	60.00	Very good	-	-	-	-
	(liquid)	12.8	87.00	Excellent	38.00	Good	1.00	Very poor	-	-	-	-
		6.4	20.00	Poor	3.00	Very poor	0	None	-	-	-	-
22	ametryne	16.0	57.50	Good	3.00	Very poor	0	None	-	-	-	-
	(wettable	8.0	0.05	Very poor	0	None	0	None	-	-	-	-
	powder)	4.0	0	None	0	None	0	None	-	-	-	-
23	bromacil	3.0	49.0	Fair	30.0	Poor	-	-	-	-	-	-
	CBM	8.0	99.0	Excellent	93.5	Excellent	-	-	-	-	-	-
	(granular)	(as bromacil)										
24	bromacil BM	3.0	55.0	Fair	10.0	Poor	-	-	-	-	-	-
	(granular)	8.0	90.5	Excellent	83.0	Very good	-	-	-	-	-	-
		(as bromacil)										
25	bromacil	4.0	86.0	Very good	12.5	Poor	-	-	-	-	-	-
	(wettable	12.0	95.0	Excellent	92.5	Excellent	-	-	-	-	-	-
	powder)											
26	prometone	5.0	29.5	Poor	1.0	Very poor	-	-	-	-	-	-
	CBM	15.0	97.5	Excellent	95.5	Excellent	-	-	-	-	-	-
	(pelleted)	(as prometone)										
27	atrazine CBM	6.0	17.25	Poor	3.5	Very poor	-	-	-	-	-	-
	(pelleted)	16.0	78.0	Very good	57.5	Good	-	-	-	-	-	-
		(as atrazine)										
			Herbicides Applied to Soil versus Gravel-Covered Soil									
27 Gravel plots	atrazine CBM (pelleted)	12.0 (as atrazine)	90.0	Excellent	85.0	Excellent	-	-	-	-	-	-
27 Soil plots	atrazine CBM (pelleted)	12.0 (as atrazine)	97.0	Excellent	60.0	Very good	-	-	-	-	-	-
14 Gravel plots	atrazine (wettable powder)	12.0 (as atrazine)	60.0	Very good	95.0	Excellent	-	-	-	-	-	-
14 Soil plots	atrazine (wettable powder)	12.0 (as atrazine)	71.0	Very good	57.5	Good	-	-	-	-	-	-

[1] Total vegetation control rating scale: Excellent = Mean control at 85 percent or greater with upper 5 percent confidence interval to 100. Very good = Mean control of 60 to 80 percent with upper 5 percent confidence interval to 100. Good = Mean control of 40 to 60 percent with upper 5 percent confidence interval to 100. Fair = Mean control of 30 to 60 percent with upper 5 percent confidence interval 70 to 80. Poor = Mean control 10 to 30 percent with upper 5 percent confidence interval 30 to 50. Very poor = Mean control of 0 to 10 percent with upper 5 percent confidence interval 0 to 30. None = Herbicide does not show detectable activity.

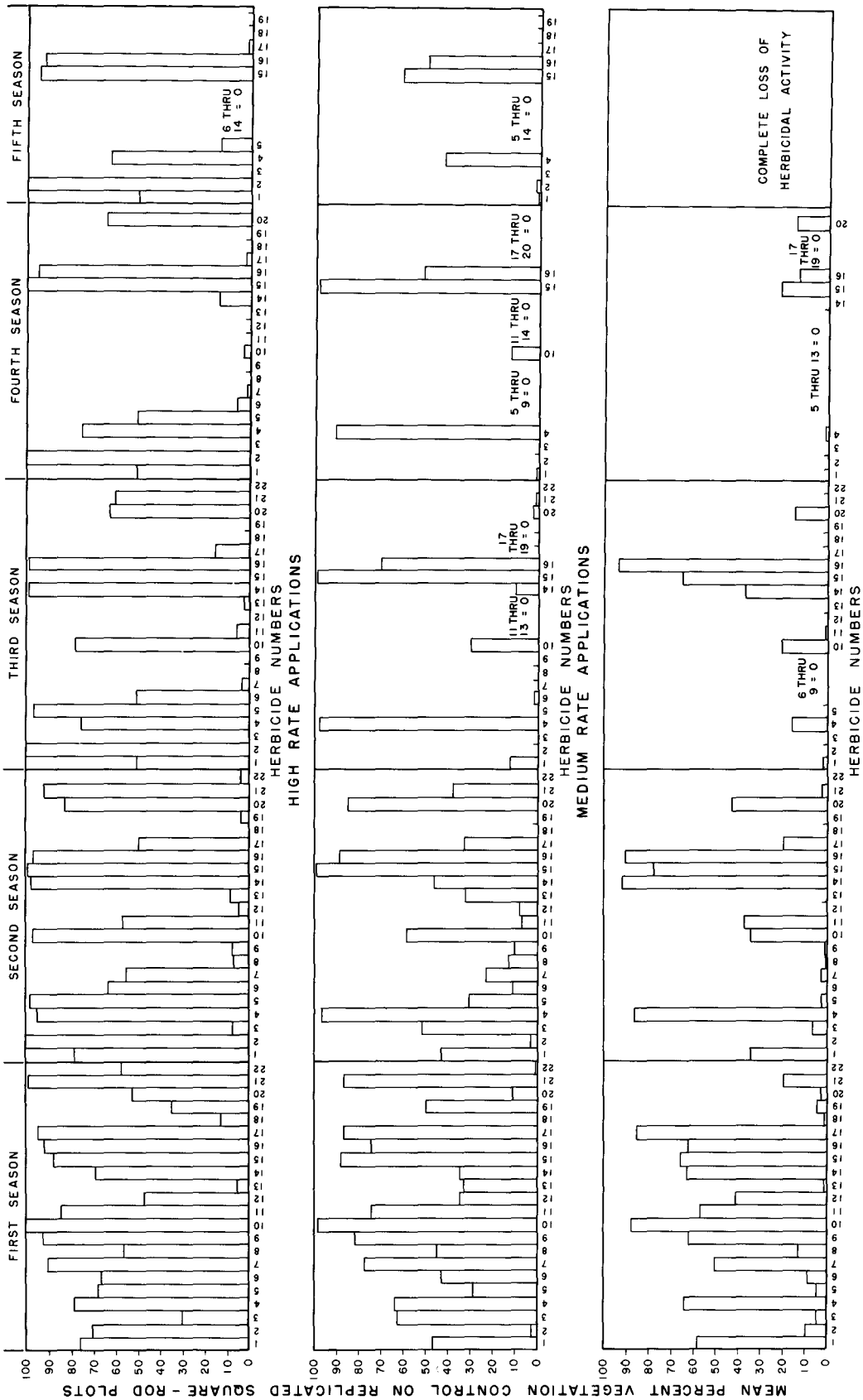

Figure 15.—Mean percent vegetation control produced over a period of three to five growing seasons by 22 soil-applied herbicides.

A number of observations can be made from table 9 and figure 15 regarding the general performance characteristics of the herbicides under test. A compound's solubility or its ability to be transported to the root zone by available moisture is an important consideration in selecting a soil-sterilant for application in an arid area. This is especially important with herbicides that are primarily root absorbed. Materials that are foliar absorbed are influenced to a lesser degree by water solubility or amounts of available moisture for transport into the soil. From table 9 it can be noted that the first season's results show that often the more soluble-type herbicides were most effective. A few typical examples would be Herbicide No. 17, which produced excellent results the first year. Four pounds of this herbicide are soluble in 1 gallon of water (water solubility of 480,000 ppm). Also, some of the inorganic-organic mixtures such as Herbicide No. 10 are quite water soluble. Prometone has a water solubility of 750 ppm. Reduced herbicidal effectiveness was observed the first year with less soluble materials, such as atrazine, Herbicide No. 14, which has a solubility of 70 ppm, and simazine that is soluble at a rate of 5.0 ppm. However, in certain instances, reduced herbicidal activity of some of the less soluble materials was overcome by higher than normal rates of application, as illustrated by diuron, Herbicide No. 2.

The limited amount of rainfall following application of herbicides during the first year of testing strongly influenced the performance of a number of these materials. The monthly rainfall patterns for the period of study at the two test sites are given in table 10. In addition, the clay soil of the test site also had a strong influence on the effectiveness of a number of these compounds, especially the low-rate applications. Herbicide manufacturers usually recommend increased rates of herbicide when applications are made on heavy soils, which might also account for better performance of high-rate applications of a number of materials. Also, a number of the herbicides under test may retain activity longer in clay soils than in sandy soil or are selectively sorbed on clay soils and show an increased residual, such as prometone. Weber et al (*15*) found that prometone was readily absorbed on montmorillonite clays, unlike other herbicides studied. However, the reverse situation can occur with materials that become so strongly sorbed to the clay as to be unavailable for plant absorption or are inactivated by chemical complexes of clays.

As the 1963 to 1967 study progressed from the second through the fourth season, a decline of herbicidal activity can be noted with the more soluble materials and some increased activity can be observed with some of the less water soluble and more persistent materials.

Table 10.—MONTHLY PRECIPITATION OCCURRING IN THE VICINITY OF THE HERBICIDE PLOTS[1]

Month	Total monthly precipitation recorded during periods of study						
	1962-1963 (inch)	1963-1964 (inch)	1964-1965 (inch)	1965-1966 (inch)	1966-1967 (inch)	1967-1968 (inch)	1968-1969 (inch)
	Denver Federal Center Test Site					Aquatic Wood Field Test Site	
September	0.33	2.07	0.41	2.59	1.18	0.54	0.50
October	0.05	0.32	0.19	0.35	0.77	0.99	0.50
November	0.80	0.16	0.57	0.31	0.39	0.62	0.81
December	0.09	0.47	0.38	0.58	0.07	0.50	0.42
January	0.73	0.30	0.82	0.09	0.64	0.16	0.22
February	0.25	0.86	0.71	0.17	0.31	0.75	0.27
March	1.90	1.32	0.99	0.14	0.49	0.65	0.50
April	0.00	1.14	1.91	0.51	3.09	1.62	0.93
May	0.33	2.39	1.44	0.33	3.73	1.82	4.59
June	5.09	0.84	2.07	1.53	2.96	1.05	4.03
July	0.46	1.38	3.84	0.69	3.77	0.05	0.53
August	2.36	0.95	0.64	0.80	1.11	1.74	1.02
Annual total	12.39	12.20	13.97	8.09	18.51	10.49	14.32
5-year average—12.81 inches						2-year average—12.41 inches	

[1] Data obtained from U.S. Weather Bureau Climatological Summary records for Colorado.

Herbicidal chemical persistence in soil or its lack cannot be attributed to physical sorptive characteristics and/or transport into the root zone alone. Compounds can be rendered ineffective for reasons such as leaching loss, volatility, and chemical and biological degradation.

Results of these studies indicate that most of the herbicides under test should be applied at median or near manufacturers' recommended rates. The low rates of application would in most instances be uneconomical from the standpoint of short duration of effectiveness. There is also some question as to the merits of applying herbicides at higher than recommended rates for the conditions existing in the test site. Generally, the data indicate that only limited extension of herbicidal longevity can be obtained with most herbicides by increasing rates of application over those normally recommended by the herbicide manufacturers. This is illustrated by data obtained during the fifth season of the 1963–67 tests, where only five of the herbicides still produce adequate vegetation control at the high rates of application, three of which still show good control at the median rates. The use of increased rates of herbicide to lengthen the period of effectiveness would have to be weighed on the economic merits of the situation. In the author's opinion, lower-rate retreatments would be more economical from the standpoint of herbicide use and possible effectiveness.

During the first season of the 1963–67 tests, there were a few instances where herbicides applied as aqueous solutions or suspension were slightly more effective than granular or pelletized formulations tested. These effects could not be observed the remainder of the study. Apparently the test site had received sufficient rainfall to carry the dry-applied materials into the root zone. Granular formulations also produced vegetation control equal to the wettable powder formulations in the 1968–69 tests. Convenience of herbicide application is a factor considered in this study, and granular or pelletized formulations would have a distinct advantage over aqueous formulations considering the aspect of application ease and ultimate herbicidal effectiveness. However, the necessity of sufficient moisture to carry the herbicide into the root zone must be considered. In any situation where the amount of expected rainfall following herbicide application might be excessively low, a post-application of water or the use of a wettable formulation application would be advisable to insure the success of the treatment.

The synthetic system used in table 9 to rate the performance of herbicides included in this study was established to assist in evaluating and reporting the results of the study. These ratings would not be considered conclusive in all situations that might exist where soil-applied herbicides are used. Obviously, the use of any one of these materials would have to be based on the conditions under which they are to be used.

A number of factors must be considered in selection and use of soil-applied herbicides to provide total vegetation control with maximum efficiency and at the lowest cost. In selecting the proper herbicide formulation and rate of application, the rainfall pattern of the application site, type of vegetation to be controlled, soil type, timing of application, convenience of treatment, economics, length of expected effectiveness, and premature or excessive leaching loss are important considerations. Similarly, in making herbicide treatments the applicator must consider if it would be advisable to remove old vegetation debris so as to reduce non-soil sorptive losses, hazards to surrounding desirable vegetation, lateral movement of the herbicide (some compounds show considerable lateral movement, see figure 3), drainage transport into areas of desirable vegetation or stream courses, and necessity of post-treatment application of water to insure good coverage or soil penetration in arid areas. Obviously, a number of the herbicides tested in these studies would be expected to vary in effectiveness under conditions other than those existing at the two study sites. It is advisable to review herbicide manufacturer's registration labels, herbicide use manuals such as Agriculture Handbook No. 269, "Herbicide Manual" (*16*) and "Herbicide Handbook of the Weed Society of America" (*17*), and local agricultural college recommendations prior to final herbicide selection and use.

Consideration must also be given to any ecological hazards that soil-applied herbicides might present to animals in contact with treated areas, as well as other plant and animal organisms outside these locations. The use of these herbicides would not produce significant degradation of the local or surrounding environment because: (1) soil-sterilant herbicides used for higher plant control exhibit low levels of animal toxicity; (2) all of the active ingredients are degradable by natural, physi-

cal, and chemical means, many are utilized by soil microorganisms, and toxic compounds are not amplified through food chains; (3) extreme care is usually practiced in placing these herbicides so as to prevent surface carry-off to areas of desirable vegetation and into drainage areas; (4) soil fixation characteristics of the material restrict movement outside the treated areas; and (5) areas normally treated are small, and access to these locations is often restricted by fencing or remoteness.

SUMMARY

Twenty-seven herbicide formulations were evaluated for their ability to provide total vegetation control. These herbicides were applied to replicated 1-square-rod plots at three rates of application. This study was conducted on the Denver Federal Center reservation and the Aquatic Weed Field Test Station, on land which is primarily high plains grassland in vegetative character.

Observational ratings of test plots during the initial 5-year study indicated that a triazine herbicide, a substituted urea compound, and a uracil compound were most effective in controlling all plant growth. A number of the inorganic herbicides formulated with and without organic ingredients reflected a continual loss of herbicidal effectiveness between the first and third years. Most of the high- and median-rate applications of all herbicides showed a reduction in activity by the end of the fourth year of testing. None of the low-rate applications produced adequate vegetation control beyond the third year of exposure. These data indicate that low-rate herbicide treatments would not give satisfactory long-term control when applied under conditions similar to those occurring at the test site. Also, the high application rates did not greatly extend the effective longevity of the herbicides above the median rate or those approximating manufacturers' recommendations, except in the case of the substituted urea herbicide, diuron.

Evaluation of five new herbicidal formulations that became available since the inception of the original tests (1963–67) revealed that the two granular triazine formulations were equally as effective as the original wettable powder formulations. The remaining three herbicide formulations were based on the uracil compound, bromacil. Two of the herbicides were granular formulations. All three bromacil formulations produced satisfactory vegetation control in the 1968–69 tests and produced activities equal to or better than isocil. The uracil compound tested in the 5-year study, isocil, has been dropped by the herbicide manufacturer in preference of bromacil.

A table and a graphic figure summarizing the results of the over-all performance of each herbicide at each rate of application are included in this report. This final analysis of the results shows that a number of herbicides having greater water solubility or those that are readily transported to the root zone were most effective during the first year of exposure, but exhibited continual and eventually almost complete loss of activity over 4 years. A number of the less water-soluble organics or those that have characteristics of persistent fixation to soil particles increased in effectiveness during the second and third year of exposure. A number of these herbicides began to lose effectiveness after the fourth and during the fifth year. A review of the results of this study regarding specific herbicides reveals that applications of isocil (bromacil), prometone, and diuron consistently produced the best over-all long-term vegetation control. Isocil [1], bromacil, and prometone exhibited excellent to very good plant control at both the median and high rates of treatment, whereas diuron was effective only at the high rate. Herbicides that produced notable vegetation control, with varying results, were atrazine; monuron; Herbicides Nos. 5, 10, and 20 (formulations containing inorganic compounds and substituted ureas); and Herbicide No. 21, a liquid formulation containing 2,4-D and bromacil [2]. The best plant growth control from these herbicides was observed at the higher rates of application. Often the median rates of these herbicides did not produce total control on both plot replications and lacked the persistent characteristics exhibited by isocil (bromacil), prometone, and high rates of diuron.

Data obtained from the 1963–67 study indicate little significant difference in herbicidal performance between aqueous and dry applications. The use of dry formulations is advantageous in many instances, but use of a water carrier for herbicide

[1] Isocil has been discontinued by the manufacturer.

[2] Herbicides Nos. 20 and 21 have been discontinued by the manufacturer.

Table 11.—HERBICIDE APPLICATION RATE CONVERSIONS

Application rate* Lb/acre	Conversions		
	Lb/100 sq. ft.	Lb/sq. rod	Grams/sq. meter
2	0.0045	0.013	0.02152
5	0.01147	0.031	0.5381
10	0.0229	0.0625	1.0763
15	0.0344	0.093	1.6145
20	0.0459	0.125	2.1527
30	0.0688	0.187	3.2291
40	0.0918	0.250	4.3055
50	0.1147	0.312	5.3819
60	0.1377	0.375	6.4583
70	0.1606	0.438	7.5347
80	0.1836	0.500	8.6110
100	0.2295	0.625	10.7638
200	0.4591	1.25	21.5277
300	0.688	1.875	32.2916

Conversion values

1 square rod = 272 square feet or 25.269 square meters.

160 square rods = 1 acre or 43,560 square feet or 4,046.9 square meters.

*Application rates are based on total herbicide formulation.

application or post-wetting of dry applications would be dependent on anticipated rainfall following treatment.

A limited test conducted from 1968 through 1969 showed that a dry application of pelleted atrazine on gravel aggregate was as effective as the aqueous treatment.

Data gained from the studies are being utilized to improve and update recommendations and specified use on Bureau of Reclamation projects where total vegetation control is desirable. Wider use and acceptance of many of the newer, more effective soil-sterilant herbicides was reflected in a Bureau of Reclamation project survey conducted in 1967 and included as an appendix in this report.

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APPENDIX

SURVEY OF ANNUAL SOIL-APPLIED HERBICIDE USE FOR POWER AND IRRIGATION OPERATIONS MAINTENANCE BY THE BUREAU OF RECLAMATION AND COOPERATING PROJECTS

A survey was conducted in 1967 to determine the character of soil-sterilant use within operational areas of the Bureau of Reclamation and associated independent projects. A number of these field offices have been evaluating a few of the newer soil-applied herbicides under operational conditions within recent years. This survey was conducted to summarize the results of some of these evaluations of new compounds and to provide statistical information on the use of herbicides in these noncrop situations.

Regional and project personnel responsible for irrigation and power weed control maintenance activities cooperated wholeheartedly in this survey and responded by providing all data requested. The results of this survey are listed in table A, following.

In summarizing the data in table A, the annual total use of soil-sterilant herbicides by all regions amounts to 54,602 pounds. This would involve an estimated annual expenditure of around $31,000. The polybor-chlorate-monuron formulation of Herbicide No. 5 is the most widely-applied material, with a total use of 22,999 pounds of total herbicide formulation reported. The granular formulation of atrazine was the second in total pounds applied at 13,510 pounds of total herbicide formulation. This material is relatively new and apparently is gaining acceptance in the Region 6 area, with reports of 90 to 100 percent vegetation control over a 3-year period. Regions 6 and 7 reported the greatest annual application of soil-sterilant herbicides, amounting to 21,910 and 18,348 pounds, respectively. Herbicide application rates from all reports averaged near those recommended by the manufacturers, with only six instances of lower than normal rates and eight above normal.

Most of the projects report successful use of the various herbicides, with averages of about 92 percent control through 1 year and around 81 percent vegetation control for 2 to 3 years. There were two instances of applications lasting up to 5 years, but one report of loss of effectiveness after 3 to 6 months.

Although statistical reports from surveys of this type can only be reasonable estimates, the data demonstrate clearly the types of areas treated. The reported annual precipitation from all projects averaged 16.7 inches, ranging from 2.5 to 100 inches in the extremes. From the total 45 project reports, 31 are listed as having 15 inches of precipitation or less, while only three areas had 30 inches or more. As a whole, most of the projects would be considered as arid areas. Soil types ranged from sandy to clay types, often with combinations of both. Reported vegetation types were mostly herbaceous, annual, and perennial plants, and only occasionally were woody plants involved. Type of areas treated concerns quite a wide spectrum in all regions, with 28 reports of use on power-related facilities, 25 with irrigation structures, and 16 reports of application on other project features, such as parking lots and storage areas.

Table A.—SUMMARY OF SOIL-STERILANT USE FOR MAINTENANCE OF BUREAU OF RECLAMATION PROJECTS DURING 1967

Herbicide No.[1]	Herbicide	Type of formulation[2]	Regional area[3]	Time of application	Rate Lb/acre total formulation	Total use/year, lb	Type of area treated[4]	Vegetation type	General soil type	Annual precipitation, inches	Estimate of percentage and years of control and comments on effectiveness
1	Monuron	WP	1	Spring	6	17	Power	Herbaceous-annuals	Sandy	12-13	90-95%, 2-3 years
		WP	1	Fall	32	200	Power	Herbaceous-perennials	Clay	16	100%, 2 years
		WP	1	Fall	32	100	Power	Herbaceous-perennials	Sandy	10	100%, 4 years
		WP	1	Fall	40-50	200	Power, irrigation, other	Herbaceous-annuals and woody	Combination sandy and clay	9-12	95%, 3-5 years
		WP	1	Fall	40	1,050	Irrigation, other	Herbaceous-annuals perennials	Sandy	8	98%, 2-3 years
		WP	2	Fall	20-30	600	Irrigation	Grassland	Combination sandy and clay	6-7	95-100%, 2½-3 years
		WP	2	Winter	40	300	Irrigation		Combination sandy and clay	8	70%, 3 years
		WP	2	Fall	20	300	Power	Herbaceous-perennials	Granitic soils	17	100%
		WP	4	Spring	30	No report	Power, irrigation	Herbaceous-perennials	Clay	12-14	Retreat every 2 years, discontinued use
		WP	4	No report	40	No report	Power	Herbaceous-annuals perennials	No report	9-15	2-3 years, discontinued use
		WP	7	Spring	12	500	Irrigation		Clay	18-26	95-100%
						3,267 pounds total formulation					
2	Diuron	WP	6	Spring	48-60	600	Irrigation	Herbaceous-perennials	Variety	17	75-100%, 2 years
		WP	6	Spring	60	No report	Power, irrigation	Herbaceous-annuals	Clay	12-14	3 years, discontinued use
						600 pounds total formulation					
5	BMM	Gran	2	Fall	No report	40	Power	Herbaceous-annuals perennials	Clay	10	30%, not satisfactory
		Gran	2	Fall	5-15	No report	Power	Herbaceous-annuals perennials woody	Gravel and rock	55-100	95%, rapid regrowth
		Gran	6	Spring	871	5,916	Power, other	Herbaceous-annuals perennials woody	Many	16	80%, 3 years

Herbicide No.[1]	Herbicide	Type of formulation [2]	Regional area [3]	Time of application	Rate Lb/acre total formulation	Total use/year, lb	Type of area treated [4]	Vegetation type	General soil type	Annual precipitation, inches	Estimate of percentage and years of control and comments on effectiveness
		Gran	6	Fall	653-871	2,020	Irrigation	Herbaceous-annuals perennials	Combination sandy clay	11	10-25% in drains, 75-90% in lat, 2-3 years
		Gran	7	Spring	218	1,773	Power, irrigation	Herbaceous-annuals	Combination sandy clay, 4-inch gravel	11-14	99-100%
		Gran	7	Spring	871	13,250	Power, other	Herbaceous-annuals perennials	Silt, gravel top	10-15	95-100%, 1-2 years
						22,999 pounds total formulation					
7	CBM	Gran	2	Winter	1,740	5,000	Irrigation, other	Herbaceous-annuals perennials	Clay	8	90%, 2 years
		Gran	3	Summer	871-1,740	200	Power	No report	Sandy	2.5	85-95%, 5 years
		Gran	6	Spring	871	408	Power, irrigation	Herbaceous-annuals perennials	Sandy	13	80%, 2 years
		Liquid	1	Spring	17	34	Power, other	Herbaceous-annuals	Gravel or sandy	31	100%, first year
						5,642 pounds total formulation					
9	BM (2,3,6-TBA)	Gran	1	Fall	250	1,500	Other	Herbaceous-perennials	Sandy	10	90%, 3 years
						1,500 pounds total formulation					
11	Monuron TCA	Gran	6	Fall	178-534	1,958	Power, irrigation, other	Herbaceous-annuals perennials	Clay	15-18	95-100%, 3-4 years
						1,958 pounds total formulation					
13	Simazine	WP	2	Fall	7.2	48	Power, irrigation	Herbaceous-annuals perennials	Clay	10	30%
		WP	2	Fall	3-4	1,200	Power, irrigation, other		Sandy and clay	10-12	90-95%, 2 years
		WP	6	Spring	15-20	65	Irrigation	Herbaceous-annuals perennials	Sandy	14-16	50-95%, 2 years

		WP	7	Spring	4	25	Others	Herbaceous and woody	Clay	22-24	95-100%, during growing season
						1,338 pounds total formulation					
14	Atrazine	WP	1	Spring	As on label	100	Irrigation, power, other	Herbaceous-annuals perennials	Clay	8	33%, 3-6 months
		WP	2	Fall	8	80	Power, irrigation	Herbaceous-annuals perennials	Clay	10	30%
		WP	4	Spring	10-15	100	Power, irrigation	Herbaceous-annuals	Clay, gravel cover	12-14	100%, 3 years
		WP	4	No report	10-15	400	Power	Herbaceous-annuals perennials	Various, well-drained	9-15	Used only 1 year
						680 pounds total formulation					
20	CBDM	Gran	3	Fall	871	1,000	Irrigation, other		Clay	8	75%, 2 years
						1,000 pounds total formulation					
Not tested	Atrazine (gran form)	Gran	6	Spring	327	10,500	Power	Herbaceous-annuals perennials	Variable texture	16-24	90-100%, 3-5 years
		Gran	6	Spring	871	210	Other, irrigation	Herbaceous-annuals perennials	Sandy and clay loam	13	90%, 3 years
		Gran	7	Spring	109	2,800	Power	Herbaceous-annuals	Combination sandy and clay	11-14	100%, 1 year
						13,510 pounds total formulation					
Not tested	Bromacil (WS)	Soluble powder	3	As required	15-20 10-15	800	Irrigation, others	Herbaceous-annuals perennials	Clay	8	90%, 2 years
Similar to No. 4	Bromacil	WP	1	Spring	As on label	25	Power, irrigation	Herbaceous-annuals	Clay	8	50%, 2-3 years
						825 pounds total formulation					
See No. 5	Prometone	Gran	1	Fall	43	100	Power	Herbaceous-annuals	Sandy	12-14	95%, 1 year
		Gran	2	Fall	1,089	33	Other	Herbaceous-annuals perennials	Clay	50	25%, rate will increase in 1968
		Gran	3	Fall	871	500	Irrigation, other		Clay	8	90%, 2 years
		Gran	5		871	250	Other	Herbaceous-annuals perennials	Gravel over soil	25	No results first year

Herbicide No.[1]	Herbicide	Type of formulation [2]	Regional area [3]	Time of application	Rate Lb/acre total formulation	Total use/year, lb	Type of area treated [4]	Vegetation type	General soil type	Annual precipitation, inches	Estimate of percentage and years of control and comments on effectiveness
						883 pounds total formulation					
16	Prometone	Liquid	3	As required	7.5-10	150	Irrigation, other	Herbaceous-annuals perennials	Clay	8	90-95%, 2 years
		Liquid	6	Spring	30	250	Power, other	Herbaceous-annuals perennials	Clay	16	100%, first year
						400 pounds total formulation					

[1] See materials and methods for description of the same or similar compounds tested in 5-year study.

[2] Type of formulations: WP = wettable powder; Gran = dry formulations (granular, powder, and crystal).

[3] Regional areas of the Bureau of Reclamation, dividing 17 Western States according to drainage basins, and including all or portions of States as follows:

1. Washington, Idaho, Oregon, Montana, and Wyoming.
2. California, Oregon, and Nevada.
3. Arizona, California, Nevada, New Mexico, and Utah.
4. Nevada, Utah, Arizona, Colorado, New Mexico, and Wyoming.
5. Texas, Oklahoma, New Mexico, Colorado, and Kansas.
6. Montana, Wyoming, North and South Dakota.
7. Colorado, Nebraska, Kansas, and Wyoming.

[4] Types of areas treated for total vegetation control:

Power—Switchyards, transmission towers and pole lines, substations, and powerplant areas. Often, these areas are gravel-covered.

Irrigation—Around irrigation structures, canal banks, canal right-of-way, and occasional use on small laterals under and around lined areas. Also, occasionally used prior to lining larger canals.

Other—Equipment storage lots, building areas, parking lots, and occasionally on and around dam and reservoir sites.

ABSTRACT

Twenty-seven soil-applied herbicide formulations were evaluated for ability to provide complete vegetation control in an arid area. Observational ratings of test plots indicate that the herbicides prometone and isocil consistently produced the best over-all plant control at median and high rates of treatment over a period of 5 years. Diuron provided excellent control at the high rate only. Low-rate applications were not effective beyond 3-years' exposure. Bromacil was evaluated subsequent to the initial 5-year tests and found to be equal to isocil. Granular formulations of prometone, atrazine, and bromacil were equally as effective as the wettable powder formulations. Atrazine, monuron, 3-herbicide formulations containing mixtures of chlorates, borates, and substituted ureas produced notable vegetation control for 3 to 5 years, but with variable results. A summary of over-all performance of each herbicide and rate of application is presented. The report contains an appendix summarizing the results of a survey on annual soil-sterilant use on Bureau of Reclamation projects. This study was conducted to provide information useful to project operating personnel for improving recommendations and selection of herbicides for long-term vegetation control.

DESCRIPTORS—*weed control/ *soil-sterilants/ herbicides/ weeds/ soil treatment/ vegetation/ operation and maintenance/ performance tests/ field tests/ solubility/ chemicals/ statistical analysis/ semiarid land/ plant (botany)/ alluvial deposits/ atmospheric precipitation/ research and development/ organic compounds.

IDENTIFIERS—nonselective herbicides/ root zone/ uracil herbicides/ triazine herbicides/ substituted urea herbicides/ chlorate-borate herbicides.

☆U.S. GOVERNMENT PRINTING OFFICE: 1970 O—376-457