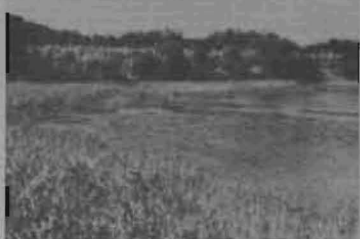
EIAC COPY

MISCELLANEOUS PAPER A-80-2



EVALUATION OF CONTROLLED RELEASE HERBICIDES IN OUTDOOR POOLS

By J. A. Foret and J. R. Barry

University of Southwestern Louisiana
Lafayette, La. 70501

September 1980
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DACW39-74-C-0074

Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
Miscellaneous Paper A-80-2		

4. TITLE (and Subtitle)

EVALUATION OF CONTROLLED RELEASE HERBICIDES IN OUTDOOR POOLS

5. TYPE OF REPORT & PERIOD COVERED

Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

J. A. Foret
J. R. Barry

8. CONTRACT OR GRANT NUMBER(s)

Contract No. DACW39-74-C-0074

9. PERFORMING ORGANIZATION NAME AND ADDRESS

University of Southwestern Louisiana
Lafayette, La. 70501

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

Aquatic Plant Control Research Program

11. CONTROLLING OFFICE NAME AND ADDRESS

Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE

September 1980

13. NUMBER OF PAGES

38

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

U. S. Army Engineer Waterways Experiment Station
Environmental Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic plant control
Aquatic plants
Controlled release herbicides
Coontail
Copper sulfate
Egeria
Evaluation
Fenac
Herbicides
Hydrilla
2,4-dichlorophenoxyacetic acid
Water hyacinths
Water milfoil

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Three controlled release (CR) chemical herbicide formulations were tested in outdoor pools for control of several aquatic plant species. The chemicals were formulations of 2,4-D, copper sulfate, and fenac, and the plant species used were waterhyacinth, egeria, Eurasian watermilfoil, hydrilla, and coontail. Although preliminary, the results showed a general decrease in normal plant growth. Conclusive results could not be determined due to various problems

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

that arose during the conduct of the study. It is recommended that small-scale field trials of these CR formulations be continued.

PREFACE

The work described in this report was performed under Contract No. DACW39-74-C-0074 between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., and the University of Southwestern Louisiana, Lafayette, La. The work was sponsored by the Office, Chief of Engineers, U. S. Army.

The work was monitored at WES in the Mobility and Environmental Systems Laboratory (MESL), under the general supervision of Mr. W. G. Shockley, Chief, MESL, and Mr. B. O. Benn, Chief, Environmental Systems Division, and under the direct supervision of Mr. J. L. Decell, Chief, Aquatic Plant Research Branch. The Aquatic Plant Control Research Program (APCRP) is now assigned to the Environmental Laboratory of which Dr. John Harrison is Chief. Mr. Decell is now manager of the APCRP.

Commanders and Directors of WES during the period of the contract and preparation of the report were COL. J. L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

EVALUATION OF CONTROLLED RELEASE HERBICIDES IN OUTDOOR POOLS

PART I: INTRODUCTION

1. The concept of controlled release of chemical compounds is currently being utilized in agriculture, in medicine, in the maritime industry, and in many disciplines of science. Presently, experimental herbicides are being formulated as mixtures in rubber, in clay, as polymers, and encapsulated in polyethylene for testing to determine their value in aquatic weed control.[1-5]

2. Release rate and release life are important aspects of controlled release aquatic herbicides. These will affect both the efficacy and the legality in terms of permissible herbicide levels within the aquatic environment. Consequently, before these herbicides may be extensively field tested, data must be collected in both laboratory and in outdoor pool studies.

3. Laboratory studies demonstrating the "chronicity phenomenon" were reported by Cardarelli,[6] Janes,[7] and Quinn and Cardarelli.[8] The principle involved control of aquatic weed species through continued exposure to low concentrations of herbicide. This principle of weed control would be desirable in field situations, but it would be difficult or perhaps impossible to achieve with conventional herbicide formulations. Controlled release formulations, however, may provide this capability. Laboratory studies by Janes[4] and Harris[2] with certain controlled release formulations indicate release rates and durations which merit testing for aquatic weed control.

4. The research reported herein was conducted in outdoor pools and represents a step beyond the laboratory phase in testing of controlled release formulations for aquatic weed control. In this research an effort was made to determine both the phytotoxic and chronic application rates of three controlled release herbicide formulations. The value of controlled release formulations for abatement-type control in aquatic situations is considered.

5. Periodic water analyses provided information on the release life of the herbicides, and these data also aid in interpretation of weed control evaluations obtained during the course of the experiments. Although data obtained from the small outdoor pools utilized in this study cannot be projected to all aquatic situations, the data do serve as a basis for more precise determination of treatments to be included when field testing controlled release herbicides.

PART II: EXPERIMENTAL PROCEDURE

Controlled Release Herbicides

6. Three controlled release herbicide formulations were tested for efficacy in experiments conducted in 1976 and 1977 at the University of Southwestern Louisiana Farm Laboratory. The herbicide formulations and application rates tested are described as follows:

- a. CBL 14 ACE-B, a rubber-2,4-D combination containing 18.7 percent butoxyethanol ester of 2,4-D, was provided by Creative Biology Laboratory of Barberton, Ohio. This formulation is reported by the developer to have a release life of 2 years. Application rates tested in 1976 were 10, 20, and 40 mg/ℓ (weight formulation : weight water). Rates tested in 1977 were 5 and 25 mg/ℓ. The concentration of active 2,4-D initially applied may be obtained by multiplying the rates of formulation used by 18.7 percent.
- b. CBL E51, a rubber-copper sulfate monohydrate combination containing 17 percent Cu^{++} with a release life of 5 to 7 months, was also provided by Creative Biology Laboratory. Rates tested in 1976 were 25, 50, and 100 mg/ℓ. In 1977, test rates of E51 were 10 and 25 mg/ℓ. The concentration of copper ion applied initially may be calculated by multiplying the formulation rates by 17 percent.
- c. Fenac-polyethylene wafers containing 20 percent fenac acid, 70 percent polyethylene, and 8 percent iron oxide were made available by Dr. Frank Harris of Wright State University, Dayton, Ohio. Rates of the fenac-polyethylene formulation tested in 1978 were 30 and 60 mg/ℓ. In 1977, rates of 10 and 40 mg/ℓ were tested. Rates of active fenac acid applied initially may be determined by multiplying formulation rates by 20 percent.

Experimental Pools

7. Thirty pools approximately 3 m square by 0.5 m deep were constructed by excavation and building earthen levees around the excavated area. After the pools were constructed, each was lined with a layer of 6 mil Monsanto 602 clear polyethylene film. A second sheet of 6 mil black polyethylene was laid over the clear film to deter leakage; however, several pools did lose water through the plastic liners during the course of the experiment. In 1976, raccoons and dogs often entered the pools and punctured the liners. This problem was partially corrected by fencing the pool area.

8. Pools were then filled to a depth of 0.4 m for the 1976 study and maintained at this level by periodic addition of tap water. This provided an average volume of 3.6 m^3 during the 1976 experiment. The pools were dug slightly deeper and lined with new film for the 1977 experiment. A water volume of 3.8 m^3 was maintained in the pools for this test. Depressions were made in the pool walls to allow drainage down to the desired volume after heavy rains. An overall view of the experimental pools is shown in Figure 1.

Establishment of Aquatic Macrophyte Species

9. The aquatic macrophyte species included in this study were egeria (*Egeria densa* Planch.), hydrilla (*Hydrilla verticillata* Royle), Eurasian watermilfoil (*Myriophyllum spicatum* L.), coontail (*Ceratophyllum demersum* L.), and waterhyacinth (*Eichhornia crassipes* (Mart.) (Solms)). These species were chosen because they are particularly troublesome in Louisiana and throughout many other regions of the country.

10. The four submersed species were established in individual flats containing a 50:50 mixture of silt loam soil and coarse sand. Twelve vigorous strands of each species were planted in the respective flats and then placed into pools. Two flats of each species were used per pool. Steiner solution,[9] a complete nutrient solution providing both macro and micro elements, was then applied at a rate equivalent of

Figure 1. Experimental pools

1 percent of the pool volume or 38 litres per pool. All species were allowed to grow for 2 to 3 weeks before application of the controlled release herbicides. Three plots (pools) were used for each herbicide treatment and for the nontreated check. All data discussed herein represent averages for three plots. Controlled release herbicides were applied on July 29 in 1976 and on July 27 in the 1977 study.

Data Collection and Analysis

Visual ratings

11. Visual ratings of weekly growth were based upon a scale of 0 to 10 where 0 represented the most vigorous plant colonies and 10 represented complete destruction of the weed colony. Values between 0 and 10 indicated intermediate control level. Visual evaluations were made by two observers working independently, and their ratings were averaged for three plots.

12. During the 1976 experiment visual ratings were made on

August 25, September 19, and October 25. In 1977, plots were rated on August 11 and 18, September 16, and October 20. After the October ratings, weed growth was halted by cold weather and further ratings would have provided no advantage.

Dry matter determinations

13. To provide more objective information upon growth of the aquatic test plants, biomass measurements were performed as a part of the 1977 experiment. On November 7 the pools were drained; and the living biomass (stems and foliage) for each species was separated, drained, and weighed to obtain fresh weights. Fresh weights for waterhyacinth are reported herein; however, dry weights for the four submersed species were obtained by oven drying 100-g samples and calculating percentage dry matter. The dry weight for a species was then determined by multiplying the percent dry matter by the fresh weight for the appropriate pools.

Data collection for subterranean tubers

14. On November 8, 1977, flats containing the roots of hydrilla were washed over a coarse screen to obtain the subterranean tubers. The tubers collected were then air dried, counted, and weighed.

Herbicide residue analyses

15. During the course of the 1976 experiment, water samples were collected from each pool on July 29; August 6, 13, and 27; September 17; and November 12. The samples were frozen until analyses for 2,4-D, fenac, and copper residues could be performed. The procedures for 2,4-D and fenac extraction and gas chromatographic analysis were those outlined by Frank and Bartley.[10] Copper analyses were performed directly from the water samples by means of atomic absorption spectroscopy.

16. Water samples for the 1977 residue analyses were collected and frozen on July 27; August 3, 10, and 24; September 1, 13, and 28; and October 28. These samples were analyzed by the same procedures utilized in 1976.

Other data collected

17. In 1976, the pH of the pool was recorded on August 5, 23, and

30 and on September 7 and 21. In 1977, pH, dissolved oxygen, and water temperature were obtained for each pool. Rainfall data were also recorded throughout the 1977 experiment. Tables 1-3 present these data in tabular form. This information may aid in the interpretation of herbicide release rates, residue dilution, and other data collected during the course of these experiments.

PART III: RESULTS AND DISCUSSION

Egeria

18. Egeria proved to be the least vigorous of the submersed aquatic species. Growth of egeria during August was limited in both 1976 and 1977. High light intensity and/or high temperatures (Table 2) in the shallow pools may have adversely influenced growth. In addition, egeria was perhaps not as efficient in the competition for nutrients as the other aquatic species.

19. Based upon visual observations made during 1976, growth of egeria was most severely affected by the E51 rubber-$CuSO_4$ and the polyethylene-fenac formulations (Table 4). All rates of these formulations proved to be highly effective, and the 60-mg/ℓ application rate of polyethylene-fenac completely eliminated egeria by the October 25 rating. Egeria was not significantly affected by the rubber-2,4-D formulation at any rates tested.

20. In the 1977 experiment, lower herbicide rates were tested in an effort to study the chronicity phenomenon. In Table 5, the visual ratings on the October 20 evaluation show that egeria was completely eliminated by the polyethylene-fenac formulation at 40 mg/ℓ, and that significant abatement resulted where the 10-mg/ℓ rate was used. In this study the rubber-$CuSO_4$ formulation at rates of 10 and 25 mg/ℓ did not affect growth of egeria. The rubber-2,4-D formulation at 25 mg/ℓ suppressed growth slightly compared with that in nontreated pools.

21. Complete control of a species appears to be a function of herbicide concentration and time of exposure. The lower rates of copper and 2,4-D appeared to have no adverse chronic effects upon egeria. The 10-mg/ℓ application of polyethylene-fenac did retard egeria growth at low concentrations and was perhaps an example of an abatement type of control at a chronic herbicide level.

Hydrilla

22. Hydrilla grew profusely in the pools and was by far the

dominant species. In 1976, growth of hydrilla was most severely retarded by the copper and fenac formulations, but it was not affected by the 2,4-D formulation (Table 6).

23. In the 1977 experiment, growth of hydrilla was most severely inhibited by the polyethylene-fenac formulation applied at 40 mg/ℓ (Table 7). As indicated in Table 8, the development of subterranean tubers in pools treated with the fenac formulation was reduced substantially compared to that for other treatments. Inhibition of subterranean tuber development would be a significant advantage in a herbicide control program for hydrilla.

Eurasian Watermilfoil

24. Eurasian watermilfoil was completely eliminated from the pools in both 1976 and 1977 by all rates of the rubber-2,4-D and the polyethylene-fenac formulations. The efficacy of these formulations in the control of Eurasian watermilfoil is shown in Tables 9 and 10. In 1976, rates of 25, 50, and 100 mg/ℓ of the rubber-$CuSO_4$ formulation significantly retarded growth compared to that in nontreated pools. The low rates of copper formulation tested in 1977 appeared to stimulate growth over that observed for nontreated plots. This growth stimulation may result at low copper levels since this element is essential for plant growth in trace amounts.

Coontail

25. Growth of coontail was vigorous but substantially less than that of hydrilla. In 1976, coontail was eliminated from the pools by all treatment rates of the rubber-$CuSO_4$ and polyethylene-fenac formulations (Table 11). The 2,4-D formulation reduced vigor of coontail, but did not eliminate the species from the pools.

26. Control of coontail in 1977 was limited by the low rates of herbicides applied (Table 12). The fenac-formulation applied at 40 mg/ℓ completely eliminated coontail while at 10 mg/ℓ only partial control

resulted. The extremely low copper levels account for the poor control of coontail provided by the rubber-$CuSO_4$ formulation in 1977.

Waterhyacinth

27. Growth of waterhyacinth was vigorous during both 1976 and 1977. Of the treatments tested in 1976, the rubber-2,4-D at 40 mg/ℓ; rubber-$CuSO_4$ at 25, 50, and 100 mg/ℓ; and polyethylene-fenac at 30 and 60 mg/ℓ proved most effective (Table 13). In 1977 polyethylene-fenac at 40 mg/ℓ and rubber-$CuSO_4$ at 25 mg/ℓ provided the best control of waterhyacinth (Table 14). The reduced herbicide rates used in 1977 substantially lowered the degree of control compared with that observed in 1976 where higher rates were used.

Herbicide Residues

14 ACE-B (rubber-2,4-D)

28. Table 15 shows that the average concentration of 2,4-D in pool water peaked at the August 13, 1976, sampling. Concentration of 2,4-D gradually dropped thereafter to nondetectable levels at the November 12 sampling. In the 1977 experiment, 2,4-D levels peaked 3 weeks after application of the 14 ACE-B formulation (Table 16). Levels of 2,4-D dropped quickly thereafter until the October 28 analysis when only minimal amounts of the herbicide could be detected.

29. Herbicide loss can be accounted for in several ways. Probably the most significant loss was due to overflow of pools during periods of heavy rainfall. Rainfall data presented in Table 3 show that above normal precipitation occurred during the 1977 study. Water loss through leakage also occurred, and some pools required periodic refilling which diluted the concentration of herbicide. Microbial decomposition has been reported as a significant factor in decomposition of 2,4-D and probably accounts for a part of the herbicide loss in these pools.[11,12]

30. The complete dissipation of 2,4-D within a period of

3 to 4 months indicates a release life of considerably less than the 2 years suggested by the formulator of 14 ACE-B. When comparisons are made between the release life of formulations in controlled laboratory tests and in outdoor pool tests, substantial differences may be expected. Release rates observed in these pool studies should approximate those of aquatic areas in the South during the warm season. The data in Tables 15 and 16 indicate that the aquatic environment was exposed to 2,4-D for approximately 7 weeks. This exposure period should be adequate to produce biological activity in susceptible species.

31. Residues in excess of the 0.1-mg/ℓ tolerance for 2,4-D in potable water were commonly found where application rates of formulation exceeded 5 mg/ℓ. In field situations, greater dilution due to water movement, higher rates of biological decomposition, and herbicide adsorption can be expected. Accordingly, reduced herbicidal activity might also be anticipated under field conditions where dilution, inactivation, and adsorption are greater. Barry and Foret[13] found 2,4-D levels within the 0.1-mg/ℓ tolerance for potable water where rates of 4.48 and 8.96 kg acid equivalent 2,4-D dimethylamine salt were sprayed in slowly moving waters. These spray applications in slowly moving waters represented 1X and 2X rates labeled for waterhyacinth control, which theoretically could produce residues well above 0.1 mg/ℓ. However, water analyses from this field study indicated 2,4-D residues to be in conformity with the established tolerance. Based upon these observations, the 2,4-D residues obtained in pools may be considerably higher than those that would occur in field situations. The only means of solving this residue question for controlled release formulations is by residue monitoring in the field.

CBL E51 (rubber-copper sulfate)

32. Concentrations of copper were highest during the first and second weeks after herbicide application in 1976 (Table 17). Only at this point were copper residues in excess of the 1-mg/ℓ tolerance for potable water, and these concentrations occurred only in pools that received the 100-mg/ℓ rubber-$CuSO_4$ application. Analyses conducted on November 12 indicated minute levels of copper in pools that received

25 and 50 mg/ℓ CBL E51 formulation, while residues for pools treated with the 100-mg/ℓ formulation averaged 0.29 mg/ℓ. Dissipation of copper can be accounted for by overflow loss during periods of heavy rainfall and by dilution resulting from addition of water in maintaining the desired pool volumes. Additionally, part of the copper was taken up by the test plant species and by algae that developed in the pools.

33. In the 1977 study, rates of CBL E51 were reduced to 10 and 25 mg/ℓ. Data in Table 18 show no detectable levels in pools treated with the 10-mg/ℓ rate and extremely low copper levels where rates of 25 mg/ℓ were applied.

Polyethylene-fenac wafer

34. Results of the analyses for fenac may be seen in Tables 19 and 20. Analyses for both 1976 and 1977 show that fenac residues persisted through the last sampling, or for approximately 3 months after application of the polyethylene-fenac formulation. Fenac levels for the 10-, 20-, and 40-mg/ℓ application rates peaked from 2 to 4 weeks after application and declined gradually thereafter. The peak level of fenac did not occur until the 7-week sampling in pools treated with the 60-mg/ℓ formulation.

35. The relatively high levels of fenac maintained in the pools indicated the persistency of this herbicide in an aquatic environment. A release life for the formulation of at least 3 months or more may also be indicated. All aquatic species were sensitive to the rates of the fenac formulation tested. Some species were eliminated from the pools with the higher application rates of 40 to 60 mg/ℓ, while the lower rates of 10 and 30 mg/ℓ resulted in significant abatement of growth of some species.

PART IV: CONCLUSIONS

36. The experiments described herein showed that controlled release formulations of 2,4-D BEE, copper sulfate, and fenac acid at the appropriate rates were effective for abatement of aquatic weed growth and in some instances complete elimination of test species. Degree of weed control was a function of herbicide sensitivity of the target species and concentration of the herbicide in the experimental pools.

37. Each of the three controlled release formulations were effective on some of the test species and merit field testing to determine their effectiveness under actual control situations. The rubber-2,4-D formulation completely eliminated Eurasian watermilfoil at rates as low as 5 mg/ℓ and more extensive testing for this use is indicated. Other aquatic species showed only slight sensitivity to the 2,4-D formulation. Careful monitoring of field experiments is indicated, since 2,4-D residues in excess of the 0.1-mg/ℓ permissible level for potable water were found at application rates as low as 5 mg/ℓ.

38. The polyethylene-fenac formulation at the 60-mg/ℓ rate eliminated egeria, Eurasian watermilfoil, coontail, and waterhyacinth and provided significant abatement of hydrilla growth and subterranean tuber development. The broad spectrum of herbicidal activity over a range of application rates demonstrates the need for future field testing of this formulation.

39. The rubber-$CuSO_4$ formulation proved most effective at the higher application rates of 50 and 100 mg/ℓ for abatement of egeria, hydrilla, Eurasian watermilfoil, and waterhyacinth. Coontail was eliminated from the pools at these rates in 1976 by all treatment levels of rubber-$CuSO_4$ formulation. This formulation also is worthy of field testing. Copper residues exceeded the 1-mg/ℓ tolerance for potable water for a short period where the 100-mg/ℓ application rates were used. Careful monitoring of any field tests for copper residues would be imperative where application rates of 100 mg/ℓ are used.

40. The logical step beyond these pool studies is field testing the controlled release herbicides. Data obtained from this research

can serve as a pattern for establishing rates of application and for monitoring residues in future field testing operations.

REFERENCES

1. Bille, S. M., Mansdorf, S. Z., and Cardarelli, N. F., "Development of Slow Release Herbicide Materials for Controlling Aquatic Plants," Final Report, Contract DACW-70-C-0030, Department of the Army, Office, Chief of Engineers, Washington, D. C., July 1970.

2. Harris, F. W., "Characterization and Evaluation of Polymers Containing Herbicides as Pendant Side Chains," Proceedings, Research Planning Conference on the Aquatic Plant Control Program, Atlantic Beach, Florida, pp 201-216, 19-22 October 1976.

3. Harris, F. W., Norris, S. O., and Post, L. K., "Factors Influencing Release of Fenac from Polyethylene Matrices," Weed Science, Vol 21, July 1973, pp 318-321.

4. Janes, G. A., "Development and Evaluation of Controlled Release Herbicides," Proceedings, Research Planning Conference on the Aquatic Plant Control Program, Atlantic Beach, Florida, 19-22 October, 1976, pp 217-220.

5. Stewart, K. K., and Nelson, L. L., "Evaluation of Controlled Release PVC and Attaclay Formulations of 2,4-D on Eurasian Watermilfoil," Hyacinth Control Journal, Vol 10, 1972, pp 35-38.

6. Cardarelli, N., "Hypothesis Concerning Chronic Intoxication of Aquatic Weeds," International Controlled Release Pesticide Symposium, College of Science and Engineering, Wright State University, Dayton, Ohio, 1975, pp 344-357.

7. Janes, G. A., "Aquatic Weed Abatement with Controlled Release Herbicides," Chemical Marketing and Economic Reprint, National Meeting, American Chemical Society, San Francisco, California, 29 August - 3 September 1976.

8. Quinn, S. Q., and Cardarelli, N. F., "Aquatic Herbicides Chronicity Study," Annual Report, Contract DACW73-72-C-0031, Department of the Army, Office, Chief of Engineers, Washington, D. C., 30 July 1972.

9. Steiner, A. A., "Soilless Culture," Proceedings of the 6th Colloquium of the International Potash Institute, Florence, Italy, 1968.

10. Frank, P. A., and Bartley, T. R., "Proposed Monitoring Guidelines for Determining Herbicide Residues in Flowing Water for Use-Registration," Interagency Ad Hoc Committee on Use of Herbicides in Aquatic Sites.

11. Evans, W. C. et al., "Bacterial Metabolism of 2,4-D Dichlorophenoxyacetate," Biochemical Journal, 122:543-51, 1971.

12. Tiedja, J. M. et al., "2,4-D Metabolism: Pathway of Degradation of Chlorocatecols by Arthrobacter sp." Journal of Agricultural and Food Chemistry, 17:1021-26,1969.

13. Barry, J. R., and Foret, J. F., "Time Course Studies on 2,4-D Amine Residues in Slow Moving Waters," Technical Report-A-79-1, April 1979, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

pH of Pool Waters Recorded During the 1976 Experiment

Treatment	Date Tested				
	8-5-76	8-23-76	8-30-76	9-7-76	9-21-76
Nontreaded check	8.5	8.1	8.5	8.0	8.2
14 ACE-B at 10 mg/ℓ	8.1	8.1	8.8	8.6	8.1
14 ACE-B at 20 mg/ℓ	7.9	7.7	8.6	8.0	7.9
14 ACE-B at 40 mg/ℓ	8.1	7.6	8.9	8.3	8.1
E51 at 25 mg/ℓ	6.8	8.1	9.1	8.4	8.1
E51 at 50 mg/ℓ	6.8	7.7	9.1	8.7	8.0
E51 at 100 mg/ℓ	6.8	7.2	8.0	8.0	7.6
Fenac wafer at 30 mg/ℓ	8.1	8.3	9.1	8.2	7.7
Fenac wafer at 60 mg/ℓ	8.4	7.8	8.7	8.5	8.1

Table 2

ph, Dissolved Oxygen, and Water Temperatures Recorded in Pools During the 1977 Experiment

Treatment	Date Sampled	Dissolved Oxygen, mg/ℓ	pH	Temperature °C
Nontreated pools	8-18-77	---	8.1	30
	8-25-77	8.3	7.7	30
	9-2-77	7.2	8.7	33
	9-14-77	8.5	7.1	27
	9-28-77	---	7.1	29
	10-28-77	---	7.2	24
14 ACE-B at 5 mg/ℓ	8-18-77	---	7.7	30
	8-25-77	7.8	7.3	30
	9-2-77	7.0	8.3	34
	9-14-77	7.6	7.2	27
	9-28-77	---	7.3	29
	10-28-77	---	7.1	25
14 ACE-B at 25 mg/ℓ	8-18-77	---	7.7	31
	8-25-77	7.9	7.5	30
	9-2-77	7.6	8.7	34
	9-14-77	8.5	7.2	28
	9-28-77	---	7.4	29
	10-28-77	---	7.0	25
CBL E51 at 10 mg/ℓ	8-18-77	---	8.3	30
	8-25-77	7.9	7.3	29
	9-2-77	6.8	8.5	34
	9-14-77	7.6	7.3	28
	9-28-77	---	7.5	29
	10-28-77	---	7.3	25
CBL E51 at 25 mg/ℓ	8-18-77	---	7.8	30
	8-25-77	8.2	7.3	30
	9-2-77	7.5	8.7	34
	9-14-77	7.8	7.4	28
	9-28-77	---	7.4	29
	10-28-77	---	7.2	24
Fenac-Poly wafers at 10 mg/ℓ	8-18-77	---	7.5	29
	8-25-77	7.8	7.3	29
	9-2-77	6.5	8.0	34
	9-14-77	7.9	7.3	28
	9-28-77	---	7.3	28
	10-28-77	---	7.3	24
Fenac-Poly wafers at 40 mg/ℓ	8-18-77	---	7.9	31
	8-25-77	7.9	7.0	31
	9-2-77	8.0	8.1	34
	9-14-77	8.1	7.3	28
	9-28-77	---	7.2	28
	10-28-77	---	7.1	24

Table 3

Rainfall During the Course of the 1977 Experiment

Date	Rainfall, cm	Date	Rainfall, cm
August		September	
6	0.74	5	2.79
9	1.14	9	4.83
11	1.40	10	2.03
15	0.38	12	1.88
16	0.25	13	2.03
17	0.18	19	4.57
18	1.46	October	
19-21	5.08	2	5.84
22	2.92	19	2.28
23	0.51	20	1.27
24	4.57	November	
25	0.51	1	20.83
		9	1.14

Table 4

Effects of Controlled Release Herbicides Upon Growth of Egeria, 1976

Treatment	Date of Visual Evaluations* 8-25-76	9-19-76	10-25-76
Nontreated check	5.8	3.7	1.8
14 ACE-B at 10 mg/ℓ (rubber - 2,4-D BEE)	3.7	3.7	1.7
14 ACE-B at 20 mg/ℓ (rubber - 2,4-D BEE)	5.8	3.7	2.5
14 ACE-B at 40 mg/ℓ (rubber - 2,4-D BEE)	4.7	5.3	2.2
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	4.1	7.3	9.2
E51 at 50 mg/ℓ (rubber - $CuSO_4$)	6.5	7.7	9.3
E51 at 100 mg/ℓ (rubber - $CuSO_4$)	7.8	7.0	8.8
Fenac wafer at 30 mg/ℓ (polyethylene-fenac)	4.5	5.3	8.2
Fenac wafer at 60 mg/ℓ (polyethylene-fenac)	6.7	6.7	10.0
LSD** = 0.05	2.4	2.0	2.7
LSD = 0.01	NS†	2.8	3.7

* Ratings based upon a 0 to 10 scale where 0 = maximum vigor and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 5

Effects of Controlled Release Herbicides

Upon Growth of Egeria, 1977

Treatments	Date of Visual Evaluations*				Dry Matter Produced
	8-11-77	8-25-77	9-16-77	10-20-77	g
Nontreated check	3.0	3.0	3.5	1.0	6.3
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	2.7	3.7	3.3	0.5	11.9
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	3.3	4.7	3.3	3.3	6.2
E51 at 10 mg/ℓ (rubber - $CuSO_4$)	3.0	0.0	0.0	1.3	69.5
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	3.0	3.3	1.7	1.0	7.7
Fenac wafer at 10 mg/ℓ (polyethylene-fenac)	0.7	1.7	4.6	5.0	25.7
Fenac wafer at 40 mg/ℓ (polyethylene-fenac)	1.3	3.0	7.0	10.0	0.0
LSD** = 0.05	NS†	2.2	4.0	1.5	NS
LSD = 0.01	NS	NS	NS	2.1	NS

* Ratings based upon a 0 to 10 scale where 0 = maximum growth and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 6

Effects of Controlled Release Herbicides Upon Growth of Hydrilla, 1976

Treatment	Date of Visual Evaluations* 8-25-76	9-19-76	10-25-76
Nontreated check	2.7	0.3	0.0
14 ACE-B at 10 mg/ℓ (rubber - 2,4-D BEE)	2.0	1.7	1.0
14 ACE-B at 20 mg/ℓ (rubber - 2,4-D BEE)	2.2	1.0	0.0
14 ACE-B at 40 mg/ℓ (rubber - 2,4-D BEE)	2.7	3.7	1.0
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	1.8	5.3	2.8
E51 at 50 mg/ℓ (rubber - $CuSO_4$)	4.3	5.3	7.8
E51 at 100 mg/ℓ (rubber - $CuSO_4$)	5.5	4.7	7.0
Fenac wafer at 30 mg/ℓ (polyethylene-fenac)	1.8	2.3	4.7
Fenac wafer at 60 mg/ℓ (polyethylene-fenac)	3.7	4.3	6.0
LSD** = 0.05	NS†	3.1	3.9
LSD = 0.01	NS	NS	5.3

* Ratings based upon a 0 to 10 scale where 0 = maximum vigor and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 7

Effects of Controlled Release Herbicides

Upon Growth of Hydrilla, 1977

Treatment	Date of Visual Evaluations* 8-11-77	8-25-77	9-16-77	10-20-77	Dry Matter Produced g
Nontreated check	1.3	0.7	0.3	0.7	757
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	0.7	0.0	1.3	0.3	1013
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	3.0	2.0	2.0	3.7	661
E51 at 10 mg/ℓ (rubber - $CuSO_4$)	1.0	0.3	0.7	0.7	1365
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	1.7	0.0	0.0	1.7	541
Fenac wafer at 10 mg/ℓ (polyethylene-fenac)	0.7	2.0	4.6	4.7	329
Fenac wafer at 40 mg/ℓ (polyethylene-fenac)	3.0	3.7	6.6	8.7	87
LSD** = 0.05	1.6	1.3	2.6	2.1	NS†
LSD = 0.05	NS	1.7	3.6	2.9	NS

* Ratings based upon a 0 to 10 scale where 0 = maximum growth and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 8

Effects of Controlled Release Herbicides Upon Subterranean Tuber Development by Hydrilla

Treatment	No. Tubers/Flat	Weights/Flat, g
Nontreated check	155	30.2
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	117	21.2
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	186	30.3
E51 at 10 mg/ℓ (rubber - $CuSO_4$)	136	25.3
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	141	21.5
Fenac wafer at 10 mg/ℓ (polyethylene-fenac)	4	0.3
Fenac wafer at 40 mg/ℓ (polyethylene-fenac)	2	0.2
LSD* = 0.05	NS**	NS

* LSD = least significant difference.

** NS = not significant.

Table 9

Effects of Controlled Release Herbicides Upon Growth of Eurasian Watermilfoil, 1976

Treatment	Date of Visual Evaluations* 8-25-76	9-19-76	10-25-76
Nontreated Check	0.3	0.7	0.5
14 ACE-B at 10 mg/ℓ (rubber - 2,4-D BEE)	5.8	10.0	10.0
14 ACE-B at 20 mg/ℓ (rubber - 2,4-D BEE)	6.8	4.7	10.0
14 ACE-B at 40 mg/ℓ (rubber - 2,4-D BEE)	6.2	9.0	10.0
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	4.3	5.3	4.7
E51 at 50 mg/ℓ (rubber - $CuSO_4$)	6.7	5.0	6.5
E51 at 100 mg/ℓ (rubber - $CuSO_4$)	6.2	5.7	7.7
Fenac wafer at 30 mg/ℓ (polyethylene-fenac)	5.7	10.0	10.0
Fenac wafer at 60 mg/ℓ (polyethylene-fenac)	7.0	10.0	10.0
LSD** = 0.05	2.4	2.5	3.1
LSD = 0.01	3.2	3.5	4.2

* Ratings based upon a 0 to 10 scale where 0 = maximum vigor and 10 = complete kill.

** LSD = least significant difference.

Table 10

Effects of Controlled Release Herbicides Upon Growth of Eurasian Watermilfoil, 1977

Treatment	Date of Visual Evaluations* 8-11-77	8-25-77	9-16-77	10-20-77	Dry Matter Produced g
Nontreated check	0.0	0.0	0.0	0.0	71
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	2.3	6.0	10.0	10.0	0
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	3.3	7.3	10.0	10.0	0
E51 at 10 mg/ℓ (rubber - $CuSO_4$)	0.3	0.0	0.0	0.0	162
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	0.7	0.0	0.0	0.0	104
Fenac wafer at 10 mg/ℓ (poly-ethylene-fenac)	2.0	2.7	7.0	10.0	0
Fenac wafer at 40 mg/ℓ (poly-ethylene-fenac)	3.0	7.3	10.0	10.0	0
LSD** = 0.05	NS†	1.3	2.4	1.1	NS
LSD = 0.01	NS	1.8	3.3	2.3	NS

* Ratings based upon a 0 to 10 scale where 0 = maximum growth and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 11

Effects of Controlled Release Herbicides Upon Growth of Coontail, 1976

Treatment	Date of Visual Evaluations*		
	8-25-76	9-19-76	10-25-76
Nontreated check	4.0	0.7	3.3
14 ACE-B at 10 mg/ℓ (rubber - 2,4-D BEE)	2.3	4.3	6.3
14 ACE-B at 20 mg/ℓ (rubber - 2,4-D BEE)	3.5	4.3	6.3
14 ACE-B at 40 mg/ℓ (rubber - 2,4-D BEE)	4.2	6.0	7.0
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	7.5	9.3	10.0
E51 at 50 mg/ℓ (rubber - $CuSO_4$)	5.8	9.7	10.0
E51 at 100 mg/ℓ (rubber - $CuSO_4$)	8.8	8.3	10.0
Fenac wafer at 30 mg/ℓ (polyethylene-fenac)	4.7	7.3	10.0
Fenac wafer at 60 mg/ℓ (polyethylene-fenac)	5.8	8.7	10.0
LSD** = 0.05	2.6	2.7	3.9
LSD = 0.01	3.5	3.7	NS†

* Ratings based upon a 0 to 10 scale where 0 = maximum vigor and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 12

Effects of Controlled Release Herbicides

Upon Growth of Coontail, 1977

Treatment	Date of Visual Evaluations* 8-11-77	8-25-77	9-16-77	10-20-77	Dry Matter Produced g
Nontreated check	1.3	1.0	0.3	0.0	67
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	3.0	0.7	1.3	1.0	60
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	3.7	3.7	1.6	2.7	15
E51 at 10 mg/ℓ (rubber - $CuSO_4$)	1.0	0.7	0.7	1.7	56
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	1.7	0.3	1.0	4.0	7
Fenac wafer at 10 mg/ℓ poly-ethylene-fenac)	0.7	1.7	4.3	4.3	47
Fenac wafer at 40 mg/ℓ (poly-ethylene-fenac)	2.0	2.7	5.3	10.0	4
LSD** = 0.05	1.8	2.1	3.0	3.1	NS†
LSD = 0.01	NS	NS	NS	4.3	NS

* Ratings based upon a 0 to 10 scale where 0 = maximum growth and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 13

Effects of Controlled Release Herbicides

Upon Growth of Waterhyacinth, 1976

Treatment	Date of Visual Ratings* 8-25-76	9-19-76	10-25-76
Nontreated check	2.0	1.3	3.3
14 ACE-B at 10 mg/ℓ (rubber - 2,4-D BEE)	1.3	2.7	4.7
14 ACE-B at 20 mg/ℓ (rubber - 2,4-D BEE)	4.2	4.0	4.7
14 ACE-B at 40 mg/ℓ (rubber - 2,4-D BEE)	5.7	7.0	8.3
E51 at 25 mg/ℓ (rubber - $CuSO_4$)	4.7	8.0	8.3
E51 at 50 mg/ℓ (rubber - $CuSO_4$)	6.2	7.7	8.7
E51 at 100 mg/ℓ (rubber - $CuSO_4$)	7.3	8.7	9.0
Fenac wafer at 30 mg/ℓ (polyethylene-fenac)	3.0	5.3	9.0
Fenac wafer at 60 mg/ℓ (polyethylene-fenac)	5.8	8.7	10.0
LSD** = 0.05	2.5	3.0	2.6
LSD = 0.01	3.4	4.1	3.6

* Ratings based upon a 0 to 10 scale where 0 = maximum vigor and 10 = complete kill.

** LSD = least significant difference.

Table 14

Effects of Controlled Release Herbicides

Upon Growth of Waterhyacinth, 1977

Treatment	Date of Visual Evaluations* 8-25-77	9-16-77	10-20-77	Fresh Weight kg
Nontreated check	0.3	2.3	1.3	7.12
14 ACE-B at 5 mg/ℓ (rubber - 2,4-D BEE)	0.7	1.0	2.1	9.39
14 ACE-B at 25 mg/ℓ (rubber - 2,4-D BEE)	0.3	3.0	4.0	7.59
E51 at 10 mg/ℓ (rubber $CuSO_4$)	0.0	3.0	2.7	6.46
E51 at 25 mg/ℓ (rubber $CuSO_4$)	0.7	4.0	6.0	4.94
Fenac wafer at 10 mg/ℓ (poly-ethylene-fenac)	0.0	3.0	3.3	10.46
Fenac wafer at 40 mg/ℓ (poly-ethylene-fenac)	1.3	7.3	8.3	1.13
LSD** = 0.05	NS†	2.1	3.2	5.21
LSD = 0.01	NS	2.9	4.5	7.23

* Ratings based upon a 0 to 10 scale where 0 = maximum growth and 10 = complete kill.

** LSD = least significant difference.

† NS = not significant.

Table 15

Analyses of Water Samples from Nontreated Pools and from Pools Treated with 14 ACE-B for 2,4-D Residues in 1976

Sampling Date	Mean 2,4-D Level, mg/ℓ*			
	Nontreated Check	14 ACE-B at 10 mg/ℓ	14 ACE-B at 20 mg/ℓ	14 ACE-B at 40 mg/ℓ
7-29-76	Date of herbicide application			
8-6-76	<0.05	0.12	0.24	0.46
8-13-76	<0.05	0.19	0.47	0.69
8-27-76	<0.05	0.12	0.18	0.68
9-17-76	<0.05	<0.05	<0.05	0.46
11-12-76	<0.05	<0.05	<0.05	<0.05

* Numerical values presented represent averages for three pools.

Table 16

Analyses of Water Samples from Nontreated Pools and from Pools Treated with 14 ACE-B for 2,4-D Residue in 1977

Sampling Date	Mean 2,4-D Level, mg/ℓ*		
	Nontreated Check	14 ACE-B at 5 mg/ℓ	14 ACE-B at 25 mg/ℓ
7-27-77	Date of herbicide application		
8-1-77	<0.05	0.06	0.38
8-10-77	<0.05	0.10	0.48
8-17-77	<0.05	0.12	0.56
8-24-77	<0.05	<0.05	0.40
9-1-77	<0.05	<0.05	0.20
9-13-77	<0.05	<0.05	0.09
9-28-77	<0.05	<0.05	<0.05
10-28-77	<0.05	<0.05	<0.05

* Numerical values presented represent averages for three pools.

Table 17

Analyses of Water Samples from Nontreated Pools and from Pools Treated with CBL E51 for Copper Residues in 1976

Sampling Date	Mean Copper Levels, mg/ℓ*			
	Nontreated Check	CBL E51 at 25 mg/ℓ	CBL E51 at 50 mg/ℓ	CBL E51 at 100 mg/ℓ
7-29-76	Date of herbicide application			
8-6-76	<0.05	0.27	0.83	1.22
8-13-76	<0.05	0.19	0.35	1.47
8-27-76	<0.05	0.15	0.21	0.67
9-17-76	<0.05	0.10	0.10	0.38
11-12-76	<0.05	0.07	<0.05	0.29

* Numerical values presented represent averages for three pools.

Table 18

Analyses of Water Samples from Nontreated Pools and from Pools Treated with CBL E51 for Copper Residues in 1977

Sampling Date	Mean Copper Levels, mg/ℓ* Nontreated Check	CBL E51 at 10 mg/ℓ	CBL E51 at 25 mg/ℓ
7-27-77	Herbicide formulation applied		
8-3-77	<0.05	<0.05	0.06
8-10-77	<0.05	<0.05	<0.05
8-24-77	<0.05	<0.05	0.06
9-1-77	<0.05	<0.05	0.06
9-13-77	<0.05	<0.05	<0.05
9-28-77	<0.05	<0.05	<0.05
10-28-77	<0.05	<0.05	<0.05

* Numerical values presented represent averages for three pools.

Table 19

Analyses of Water Samples from Nontreated Pools and from Pools Treated with Fenac-Polyethylene Formulation in 1976

Sampling Date	Mean Fenac Level, mg/ℓ*		
	Nontreated Check	Fenac-Poly 30 mg/ℓ	Fenac-Poly 60 mg/ℓ
7-29-76	Date of herbicide application		
8-6-76	<0.05	0.14	0.21
8-13-76	<0.05	0.23	0.28
8-27-76	<0.05	0.13	0.30
9-17-76	<0.05	0.11	0.32
11-12-76	<0.05	0.07	0.19

* Numerical values presented represent averages for three pools.

Table 20

Analyses of Water Samples from Nontreated Pools and from Pools Treated with Fenac-Polyethylene Formulation in 1977

Sampling Date	Mean Fenac Level, mg/ℓ		
	Nontreated Check	Fenac-Poly 10 mg/ℓ	Fenac-Poly 40 mg/ℓ
7-27-77	Herbicide formulation applied		
8-3-77	<0.05	0.05	0.25
8-10-77	<0.05	0.06	0.29
8-17-77	<0.05	0.06	0.25
8-24-77	<0.05	<0.05	0.19
9-1-77	<0.05	0.05	0.21
9-13-77	<0.05	<0.05	0.16
9-28-77	<0.05	<0.05	0.20
10-28-77	<0.05	<0.05	0.15

* Numerical values presented represent averages for three pools.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Foret, James A
Evaluation of controlled release herbicides in outdoor pools / by J. A. Foret, J. R. Barry, University of Southwestern Louisiana, Lafayette, La. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
18, 20 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; A-80-2)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-74-C-0074.
References: p. 17-18.

1. Aquatic plant control. 2. Aquatic plants. 3. Controlled release herbicides. 4. Coontail. 5. Copper sulfate. 6. Egeria. 7. Evaluation. 8. Fenac. 9. Herbicides. 10. Hydrilla. 11. 2,4-dichlorophenoxyacetic acid. 12. Water hyacinths. 13. Water milfoil. I. Barry, J. Robert, joint author. II. Louisiana. University of Southwestern Louisiana, Lafayette. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; A-80-2.
TA7.W34m no.A-80-2