USDA Technical Report on Controlling

Hydrilla Verticillata

By ROBERT D. BLACKBURN and LYLE W. WELDON*

* Botanist and Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Fort Lauderdale, Fla.

HYDRILLA *(Hydrilla verticillata* Casp.) was first discovered in the United States near Miami, Fla., in 1960. It has dispersed over the entire state and into Georgia and Alabama since its introduction.

Largest infestations in Florida are located along the southeast coast in the slow-flowing canals and conservation areas, in the central area in the clear water lakes, and in the clear water springs and rivers along the central west coast.

Since its introduction, the plant has infested more than 60,000 acres of water in the southeastern United States.

Growth of submersed vegetation is a common occurrence in Florida. Any body of water will be choked with aquatic weeds in a relatively short period. Effective control is not only necessary but essential if the water is going to be used for fish production, recreation or irrigation.

Extensive research under controlled as well as field conditions has shown that there is no universal panacea for controlling submersed aquatic weeds. Control methods must be based on the aquatic species and on the environmental conditions.

It is also necessary to take into consideration the season and the stage of development of the weed. However, it is not logical to expect the same method of control will give even approximately comparable results on all aquatic weeds or under all various climatic and soil conditions.

It is important that the species causing damage be studied intensively from the antecological and the synecological aspects. Knowledge of the plant's habitat, relation to soil and climate, method of dissemination, special plant and animal enemies, power of variability and actual distribution is necessary before work on weed control is taken up.

Research on hydrilla was initiated on a very limited scale at Fort Lauderdale, Fla., in 1962. Early research was conducted under the misconception that hydrilla was elodea *(Elodea canadensis* Michx.). Proper identification was not obtained until 1965. The realization that a new weed species had been introduced into the United States gave substantial support to the need for additional research on physiology, ecology and control.

In subtropical areas it is a very difficult task to check the growth of aquatic vegetation. There are many chemicals which have been used as aquatic herbicides in the United States. It is not advisable for the aquatic weed scientist to recommend these aquatic herbicides for the control of a plant that he knows little about or about which there is little information available in world literature. This investigation was designed to evaluate herbicides and herbicidal combinations on hydrilla in laboratory and field conditions.

Identification of Hydrilla

Hydrilla is a submersed vascular aquatic plant, rooted to the bottom with long branching stems. Lower leaves are opposite and small, whereas the medium and upper leaves are in whorls of fours and eights.

Leaves are verticillate and narrowly lanceolate. Flowers arise singularly from the spathe, and are found at or near the surface and from near the growing tip. The entire flower is inconspicuous and measures no more than four to five millimeters across the tip of a threadlike pedicel.

Seed formation is poor if it occurs at all. Reproduction is both vegetatively and by fruits. Broken shoots develop into new plants which attach themselves in the hydrosoil by fine filiform adventitious roots. Plants also produce subterranean shoots with swollen tips, densely clothed with fleshy, acute or acuminate scale-like leaves which are termed "stem tubers." An additional propagating structure, "the turion," is produced by hydrilla.

In taxonomy keys, elodea and hydrilla seem easily identifiable, but the actual plants are very difficult to distinguish. Hydrilla is referred to as an Old World genus and elodea as a New World genus. Vegetative characteristics that may be used to distinguish between the two genuses are the copiously toothed leaves of hydrilla, although elodea may often have similar teeth. The plants must be in flower to be positive of their identification.

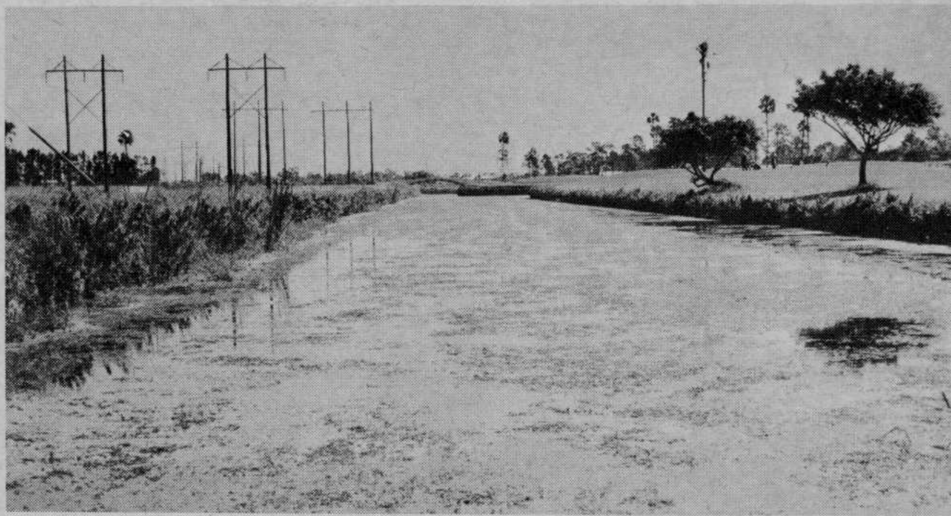
This plant is found in Russia, Prussia, Australia, Central Africa, East Asia, India and many other areas of the world. Only recently has it become established in Florida, Southern Georgia and Alabama.

Material and Methods

Still-water laboratory experiments were conducted in a temperature and light intensity controlled room to determine the effect of various herbicides and herbicidal combinations of hydrilla. Herbicides were evaluated at concentrations of 1, 5 and 10 ppmw. The visual herbicidal effect was recorded at 2, 4 and 6 weeks after treatment. A rating scale of 0 — 100 was used (0 = no effect, 100 = complete kill). Copper sulfate and 2,4-D were used as standard treatments. Technical and formulated samples of herbicides were furnished by various chemical companies. Herbicidal combinations were prepared in the laboratory.

Herbicides that showed outstanding herbicidal activity in the laboratory were further evaluated in field plots. Canals, conservation areas, and lakes with uniform infestations of hydrilla were selected as the experimental sites. Plot sizes varied depending on the size of the weed infestation in the canal or lake and the amount of herbicide made available by the company. All plots were replicated three times in each experiment. The field experiments were located along the east coast of Florida from Orlando to Homestead.

Herbicides were injected 4 to 6 in. below the water surface with a single ¾ in. off-center nozzle at an operating pressure of 125 psi. An airboat was used to apply the herbicide evenly through the plot. The desired amount of herbicide to be



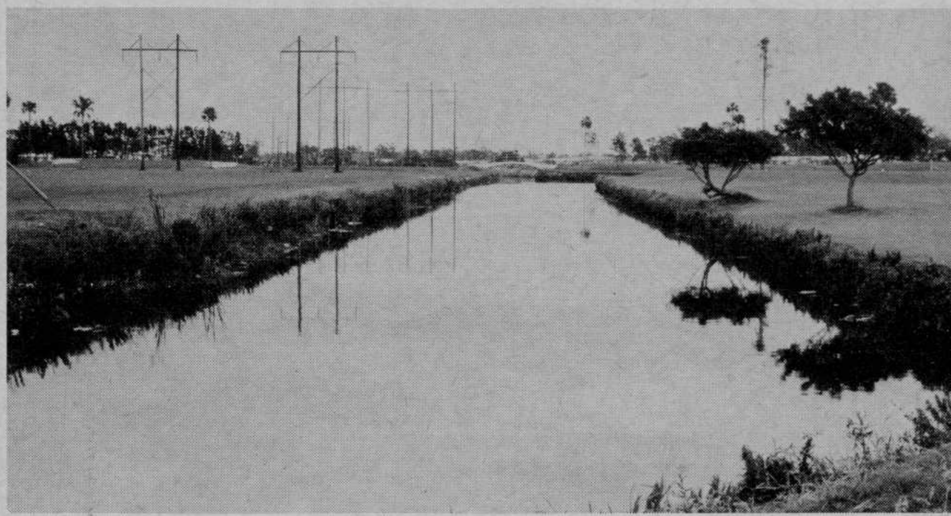


Fig. 1. A flood control canal at time of treatment (top) and the same canal two weeks after treatment with 3 ppmw of the amine salt of endothall for control of hydrilla (bottom).

Table 1. Effectiveness of selected herbicides on hydrilla in laboratory tests.

Chemical	Conc. ppmw	Percent Control — Weeks after treatment 2	4	6
2,4-D	1	0	0	0
	5	5	12	15
	10	8	23	30
2,4-D (BE ester)	1	0	0	0
	5	10	30	68
	10	25	55	83
2,4-D (Tertiary Amine)	1	20	33	55
	5	100	100	100
	10	100	100	100
Silvex (Potassium salt)	1	0	0	0
	5	7	15	28
	10	10	38	50
Silvex (10 ester)	1	10	22	35
	5	25	55	68
	10	45	75	95
Acrolein	1	60	75	10
	5	100	100	100
	10	100	100	100
Endothall	1	45	68	70
	5	75	100	100
	10	98	100	100
Endothall (dihydroxy aluminum salt)	1	30	85	93
	5	75	100	100
	10	87	100	100
Endothall (monococamine salt)	1	90	100	100
	5	100	100	100
	10	100	100	100
Endothall (dicocoamine salt)	1	97	100	100
	5	100	100	100
	10	100	100	100
Simazine	1	0	0	0
	5	7	17	45
	10	18	38	68
Ametryne	1	0	0	0
	5	47	48	80
	10	65	98	100
Diquat	1	85	100	100
	5	100	100	100
	10	100	100	100
Paraquat	1	70	98	100
	5	100	100	100
	10	100	100	100
Dichlobenil	1	0	0	0
	5	0	3	15
	10	20	35	47
Fenac	1	10	25	30
	5	22	75	95
	10	38	95	100
Diuron	1	2	38	53
	5	10	87	100
	10	17	95	100
Bromocil	1	7	10	15
	5	17	58	98
	10	30	85	100
G-14260	1	30	60	95
	5	40	75	100
	10	55	95	100
Diquat + endothall	0.5 + 0.5	37	100	100
	2.5 + 2.5	100	100	100
	5 + 5	100	100	100
$CuSO_4$	1	17	18	25
	5	38	55	68
	10	45	80	100
Chloroxuron	1	0	0	0
	5	45	85	100
	10	70	100	100
Sodium arsenite	1	30	45	50
	5	93	100	100
	10	100	100	100
Amitrole-T	1	0	0	0
	5	0	0	0
	10	5	10	10
Cupric chloride	1	30	52	53
	5	40	80	93
	10	70	100	100
Aromatic solvents	10	5	40	60
	20	50	100	100
	40	95	100	100

applied in each plot was mixed with enough water to equal 150 gpa.

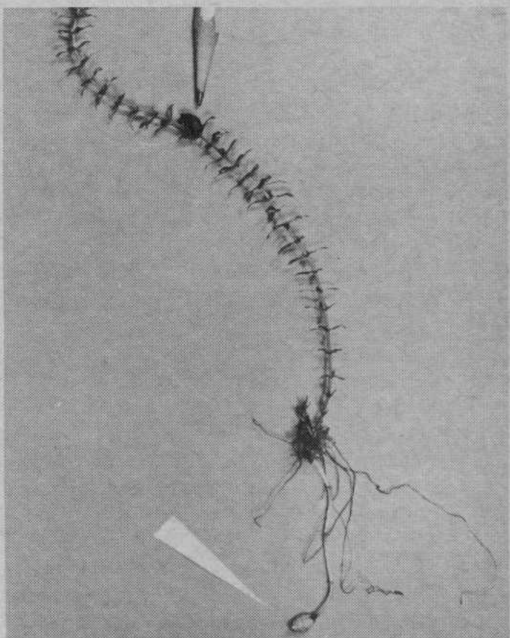
Visual evaluations were made at 2 and 4 weeks and at monthly intervals thereafter until the plot had regrown. A rating scale of 0 — 100 was used (0 = no effect, 100 = complete kill). Percentage of regrowth of the plants in the plot was also recorded at each evaluation.

Laboratory Evaluation

Results of the evaluation of 26 herbicides selected from more than 800 different herbicides evaluated on hydrilla in still-water tests are shown in Table 1. Many of the herbicides evaluated were those presently used in aquatic weed control. Less than 5% of the herbicide exhibited sufficient activity to be considered for further evaluation. The laboratory evaluations have served as a fast means of eliminating the herbicides inactive on this plant.

The similarity in appearance of hydrilla to elodea and egeria is not true when comparing methods of control. The plant is very resistant to most aquatic herbicides. To determine if the effectiveness of herbicides could be increased, evaluations were made using a combination of various herbicides. The results of three commonly used aquatic herbicides applied alone and in combinations, selected from more than 75 different combinations, are

As many as 100 turions, either axillary (pencil) or subterranean (arrow), may be produced per square foot in one growing season.



shown in Table 2. The addition of low concentrations of copper sulfate to diquat and endothall greatly increase the effectiveness of these two herbicides on hydrilla. Diquat plus copper sulfate was the most effective combination evaluated.

Field Evaluation

During the past six years, 37 different herbicides have been evaluated in small field-plot experiments on hydrilla. The results of 15 of these herbicides are shown in Table 3. The herbicides were not as active in the field as in the laboratory. It was necessary to increase the herbicidal concentration 4 to 8 times in field-plot experiments to obtain control equivalent to the laboratory. This was expected because of the dilution of herbicide out of the treated plots and other environmental factors which would not affect laboratory evaluations.

The most effective herbicides evaluated on hydrilla were acrolein, endothall cocoamine salts, aromatic solvents and copper sulfate. However, all of these herbicides are toxic to fish and other aquatic fauna at the concentrations needed to kill hydrilla. Diquat and paraquat were effective on hydrilla at concentrations of 2 ppmw, but the cost of applying this concentration would make their use prohibitive. The potassium salt of endothall was not as effective as the dihydroxy aluminum salt.

Combinations of herbicides have been very effective in other types of weed control. Laboratory results

Table 2. Effectiveness of diquat, copper sulfate, and endothall alone and in combination on hydrilla in laboratory tests.

		Percent Control		
		Weeks after treatment		
Herbicide	Conc. ppmw	2	4	6
Diquat	0.1	0	10	27
	0.25	17	35	45
	0.5	35	75	80
	0.75	37	80	95
	1.0	45	90	100
Diquat + $CuSO_4$	0.1 + 0.4	15	35	55
	0.25 + 1	37	55	87
	0.25 + 2	45	63	90
	0.25 + 4	48	75	90
	0.25 + 8	50	78	95
	0.5 + 1	37	80	98
	0.5 + 2	45	90	100
	0.5 + 4	50	97	100
	1 + 1	58	100	100
	1 + 2	60	100	100
	1 + 4	70	100	100
	1 + 8	78	100	100
$CuSO_4$	1	0	3	10
	5	27	47	65
	10	68	80	95
	20	85	100	100
Endothall	1	10	35	57
	2	50	68	85
	4	70	93	100
	8	90	100	100
Endothall + $CuSO_4$	2 + 1	50	75	80
	2 + 2	50	80	87
	2 + 4	55	80	93
	2 + 8	70	87	98
	2 + 16	75	95	100
	4 + 1	80	97	100
	4 + 2	85	100	100
	4 + 4	85	100	100
	4 + 8	90	100	100
	4 + 16	96	100	100
Diquat + endothall	0.25 + 0.25	15	25	37
	0.5 + 0.5	30	70	75
	0.75 + 0.75	45	80	99
	1 + 1	55	95	100
	2 + 2	85	100	100


Fig. 2. A small lake at time of treatment (left) and the same lake (right) three months after treatment with 1 ppmw of diquat plus 4 ppmw of copper sulfate for control of hydrilla.

Table 3. Effectiveness of 15 herbicides evaluated on hydrilla in field plot tests, expressed as percent reduction in original weed population.

Herbicide	Conc. ppmw	Percent reduction — Weeks after treatment 2	4	8	12	16	20
Diquat	1	45	65	70	55	15	0
	2	55	85	100	100	98	75
Paraquat	1	40	70	75	60	35	10
	2	50	80	100	100	100	80
Endothall (Potassium salt)	1	10	15	0	0	0	0
	2	10	17	5	0	0	0
	3	15	20	10	0	0	0
	4	20	25	10	0	0	0
	8	25	85	75	60	20	0
	16	55	100	100	96	75	55
Endothall (monococoamine salt)	1	65	85	60	40	5	0
	2	90	98	87	55	25	5
	3	98	100	95	80	50	15
	4	100	100	100	98	65	35
Endothall (dicocoamine salt)	1	75	93	70	50	10	0
	2	100	100	95	60	17	0
	3	100	100	100	85	65	20
	4	100	100	100	100	70	30
Endothall (dihydroxy aluminum salt)	2	38	72	75	50	35	20
	4	50	85	95	95	70	35
2,4-D (BE ester)	5	0	10	10	0	0	0
	10	15	30	15	5	0	0
	20	35	55	70	45	15	0
2,4-D (Tertiary amine)	2.5	35	45	20	5	0	0
	5	50	60	45	15	0	0
	10	65	85	70	50	15	0
Silvex (10 ester)	5	10	20	5	0	0	0
	10	25	40	10	0	0	0
Acrolein	4	80	90	78	50	25	0
	5	87	95	85	50	25	0
	7	98	100	95	65	35	0
	10	100	100	98	75	40	10
Aromatic solvents	10	25	15	0	0	0	0
	40	60	45	15	0	0	0
	80	100	100	75	70	25	5
	100	100	100	80	70	30	10
Fenac	2	0	15	20	10	0	0
	4	0	25	37	45	17	5
Dichlobenil	2	0	10	10	0	0	0
	4	0	10	20	10	0	0
Copper sulfate	10	10	25	10	0	0	0
	20	45	75	60	25	0	0
	40	80	85	70	40	15	0
	80	97	98	92	60	40	5
Ametryne	2.5	20	35	40	25	0	0
	5	35	50	65	45	40	25

Table 4. Effectiveness of diquat and copper sulfate applied alone and in combination on hydrilla in field plot tests, expressed as percent reduction in original weed population.

Herbicide	Conc. ppmw	Percent reduction — Weeks after treatment 2	4	8	12	16	20
Diquat	0.5	20	45	40	10	0	0
	1	50	75	60	35	10	0
	2	75	95	100	100	90	65
Copper sulfate	5	10	15	0	0	0	0
	10	13	25	40	25	0	0
	20	40	70	50	40	15	0
	40	75	85	80	50	25	10
	80	98	100	100	98	75	35
Diquat + copper sulfate	0.5 + 1	25	50	55	40	10	0
	0.5 + 2	30	60	55	40	15	0
	0.5 + 4	50	75	70	65	50	15
	0.5 + 8	50	75	75	65	55	20
	0.5 + 16	65	80	85	80	75	35
	1 + 1	65	90	90	80	55	40
	1 + 2	65	95	95	90	70	50
	1 + 4	75	100	100	100	100	90
	1 + 8	80	100	100	100	100	98
	1 + 16	90	100	100	100	100	100

had shown that a combination of diquat plus low concentrations of copper sulfate was very effective on hydrilla. The results of these combinations in comparison with each applied alone in field plots is shown in Table 4. The combinations of the copper sulfate plus diquat controlled hydrilla at economical and nontoxic-to-fish concentrations.

Diquat is widely used as an aquatic herbicide but has not been very effective on hydrilla. Copper sulfate is used as an algaecide and sometimes on submersed weeds but it is usually not favored for use in fishery waters because of its toxicity at herbicidal concentrations, and its ineffectiveness at reasonable concentrations in alkaline waters. Copper sulfate will control hydrilla but it requires concentrations of 40 to 80 ppmw. The combinations of low concentrations of these two herbicides has resulted in a very effective control for hydrilla.

Acrolein and the monococoamine salt of endothall have been used successfully in operational aquatic control programs. Some fish toxicity has been noted in most of these treatments. Toxicity can be greatly reduced if the herbicide is applied at several different times. Caution should be taken not to apply enough herbicide at any one time to build up a fish toxic concentration in the entire lake or canal. Fish have been noted to swim out of the area during herbicidal application. Acrolein should be applied at 7 ppmw and the cocoamine salt of endothall at 3 ppmw. These herbicides may also be used in flowing waters.

Diquat + copper sulfate is being used operationally for control of hydrilla in nonflowing waters. Concentrations of 1 ppmw diquat + 4 ppmw copper sulfate have given excellent control of hydrilla and other submersed species. The two herbicides must be mixed together in the spray tank before application. Control has not been as effective when applying the two herbicides separately. This combination is very corrosive to metal. Fiberglass, plastic or stainless steel spray equipment should be used when applying the herbicidal combination. This combination should not be applied with conventional aerial spraying equipment. When applied at the recommended rate the combination is not toxic to fish. When treating large areas it may be advisable to treat at two different intervals to reduce the biological oxygen demand caused by decomposing vegetation in the body of water.