THE STATUS OF DIQUAT AND PARAQUAT AS AQUATIC HERBICIDES

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ABSTRACT

The chemical and physical properties and phytocidal activity of diquat (1:1'-ethylene-2:2'-bipyridylium cation) and paraquat (1:1'-dimethyl-4:4'-bipyridylium cation) are discussed. Data are presented on the evaluation of herbicidal activity of the various salts of these 2 chemicals under controlled laboratory conditions, in plastic pools, and in earthen ponds. Research indicates that a majority of common submersed and many emergent aquatic weeds may be killed by concentrations of 0.2 to 0.5 ppm cation of these 2 chemicals. Fish toxicity studies indicate a threshold toxic concentration for diquat in excess of 10 ppm cation, and for paraquat in excess of 5 ppm cation.

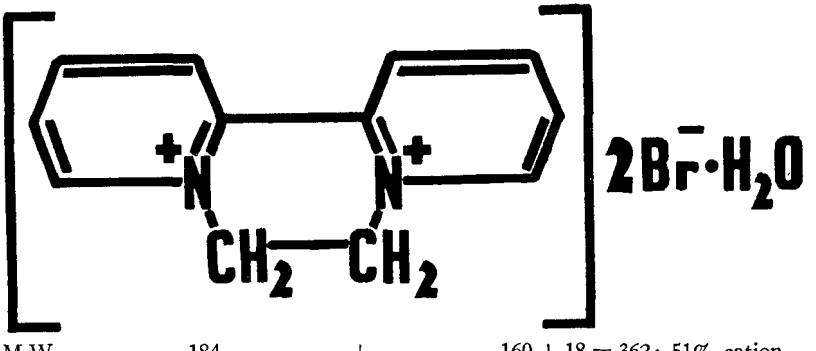
Two new quaternary bipyridyl chemicals, diquat and paraquat, have been subjected to extensive aquatic herbicide evaluation tests for the past 3 years. These tests have been conducted in the laboratory, in plastic pools, and to a limited extent in ponds, lakes, and drainage canals. The herbicidal activity exhibited under these varied conditions has been spectacular. Concentrations needed for aquatic weed control have not shown any harmful effects upon fish present in such treated waters.

Since these are relatively new herbicides, this paper includes general information on the chemicals and their development as aquatic herbicides, laboratory and plastic pool evaluations of herbicidal activity on selected submersed and emergent aquatic plants, toxicity of the various salts to several species of fresh water fish, and results of herbicidal activity in ponds.

Chemical and Physical Properties

Diquat was first synthesized by Imperial Chemical Industries in 1955. Research by Plant Protection Limited, a subsidiary of I.C.I., indicated that this chemical possessed desiccating, defoliating, and herbicidal properties, particularly on certain broadleaf terrestrial species (Calderbank, 1960; Mees, 1960). The chemical is water soluble, stable in neutral or acid solution, non-volatile as the cation or as the dibromide or dichloride salts, rapidly adsorbed when it comes in contact with soil, and apparently is not released under natural aquatic conditions. Two salts of diquat have been produced commercially. The structural formulae and molecular weights of these follow (Wessel, 1962):

Diquat dibromide, 1:1'-ethylene-2:2'-bipyridylium dibromide monohydrate



M.W. 184 + 160 + 18 = 362; 51% cation
∴ 4 pounds of diquat dibromide salt per gallon equals 2.03 pounds of diquat cation.

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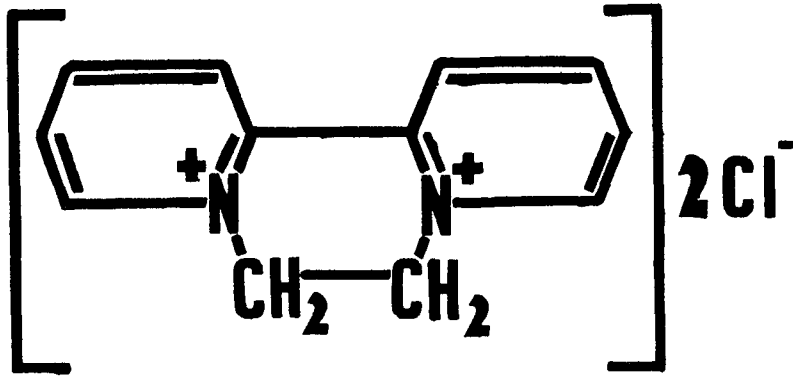
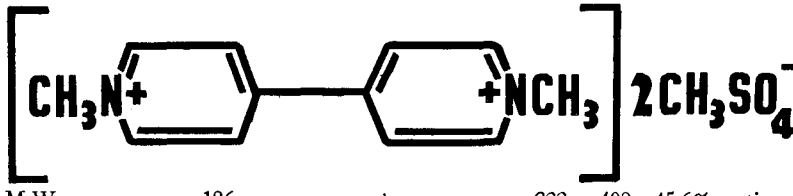
Diquat dichloride, 1:1′-ethylene-2:2′-bipyridylium dichloride



M.W. 184 + 71 = 255; 72.2% cation
∴ 2.8 pounds of diquat dichloride salt per gallon equals 2.0 pounds diquat cation.

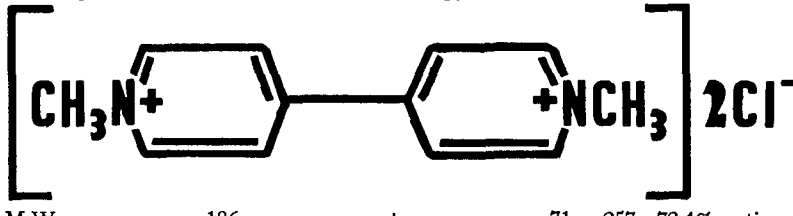
Paraquat was first synthesized by Imperial Chemical Industries in the mid 1950's. This chemical also possesses desiccating and herbicidal properties on broadleaf plants, but is more herbicidally active on grasses than is diquat. It is water soluble, stable in solutions to pH 11, non-volatile as the cation or as the di(methyl sulfate) or dichloride salts, rapidly adsorbed and inactivated when it comes in contact with soil, and apparently is not released under natural aquatic conditions. Two salts of paraquat have been produced commercially. The structural formulae and molecular weights of these follow (Wessel, 1962):

Paraquat di(methyl sulfate), 1:1′-dimethyl-4:4′-bipyridylium di(methyl sulfate)



M.W. 186 + 222 = 408; 45.6% cation
∴ 3.67 pounds of paraquat di(methyl sulfate) salt per gallon equals 1.67 pounds paraquat cation.

Paraquat dichloride, 1:1′-dimethyl-4:4′-bipyridylium dichloride



M.W. 186 + 71 = 257; 72.4% cation
∴ 2.8 pounds of paraquat dichloride salt per gallon equals 2.0 pounds paraquat cation.

Phytotoxicity

The phytotoxic action of both diquat and paraquat is rapid on the aerial parts of plants, and is directly related to the cationic concentration of either chemical. On emergent type aquatic plants, the addition of an emulsifying or wetting agent is essential for uniform coverage. The plants are not killed below soil

level, and regrowth of grasses and other perennial plants may occur. The characteristic toxicity symptoms are wilting and discoloration followed by bleaching or browning and then total collapse of the entire plant (Calderbank, 1960). The phytotoxicity of both chemicals is influenced by light. Applications made 1 to 2 hours before darkness will allow translocation of the chemical in plants but will not show characteristic herbicidal activity until the plants are again exposed to light.

Nomenclature and Availability of Chemical for Previous Research

The information presented in this section is included to clarify data on these 2 chemicals, and to permit conversion from old rates based upon salts to present-day values based upon cations.

Diquat: The first samples of this chemical to come into the United States (1959) for aquatic herbicide evaluation were designated as XY 1053/58 or FB-2. During this period Chipman Chemical Company was the associate for the development of this chemical in the United States. However, samples for use in aquatic herbicide evaluation tests were obtained from England. In 1960 the English started calling the chemical reglone, and later that same year the name was changed to diquat. During this interval California Chemical Corporation became the development associate for these chemicals in the United States. Since 1961 this Company has been a ready source of diquat for experimental purposes.

Prior to 1962 practically all samples of diquat tested had been 1:1′-ethylene-2:2′-bipyridylium dibromide monohydrate. The formulation available for experimental use contained 4 pounds per gallon of diquat dibromide salt. Thus, previously reported data on diquat was on a 4 pound per gallon diquat dibromide salt basis. Beginning January 1, 1962, formulations of this chemical contained 2.8 pounds per gallon of 1:1′-ethylene-2:2′-bipyridylium dichloride (diquat dichloride). However, because of the mode of phytocidal activity of this chemical, it has been propsed that all rate calculations be based upon 2 pounds per gallon of 1:1′-ethylene-2:2′-bipyridylium cation (diquat). Rates and concentrations expressed as diquat dibromide salt may be converted to diquat cation by multiplying by 0.51. All data on diquat presented in this paper are expressed as diquat cation.

Paraquat: The first samples of this compound, called PP-910, were made available for aquatic herbicide evaluations in 1960, and came directly from England to the authors. The chemical name of PP-910 was 1:1′-dimethyl-4:4′-bipyridylium di(methyl sulfate). In 1961 the name paraquat di(methyl sulfate) was adopted. Both of these original formulations of this compound contained 3.67 pounds per gallon of paraquat di(methyl sulfate) salt. Beginning January 1, 1962, formulations of this chemical contained 2.8 pounds per gallon of 1:1′-dimethyl-4:4′-bipyridylium (paraquat dichloride). Again it has been proposed that all calculations of treatment rates or concentrations be based upon 2.0 pounds per gallon 1:1′-methylene-4:4′-bipyridylium cation (paraquat). Rates and concentrations expressed as paraquat di(methyl sulfate) salt may be converted to paraquat cation by multiplying by 0.456. All data on paraquat presented in this paper are expressed as paraquat cation.

Evaluations of Herbicidal Activity in the Laboratory

Techniques developed at this Station to evaluate the herbicidal activity of chemicals to selected species of aquatic plants under controlled laboratory conditions were used in preliminary investigations on both diquat and paraquat (Lawrence, 1961). The species of plants used in these tests were the following:

Branched filamentous algae, *Pithophora* sp.
Southern naiad, *Najas guadalupensis*
Waterweed, *Elodea densa*
Pondweed, *Potamogeton diversifolius*
Stargrass, *Heteranthera dubia*
Alligatorweed, *Alternanthera philoxeroides*
Water hyacinth, *Eichhornia crassipes*
Duckweed, *Lemna minor*
Parrotfeather, *Myriophyllum brasiliense*

Submersed aquatic weeds tests were for 2 weeks at 75° F., 100 foot-candles, and 10-hour days. Emergent aquatic weeds tests were for 2 weeks at 80° F., 600 foot-candles, and 14-hour days.

TABLE I

AVERAGE EVALUATIONS OF HERBICIDAL ACTIVITY OF VARIOUS CONCENTRATIONS OF DIQUAT DIBROMIDE, PARAQUAT DI(METHYL SULFATE), AND MIXTURES OF DIQUAT AND PARAQUAT ON SEVERAL SPECIES OF SUBMERSED AQUATIC PLANTS IN STILL WATER TESTS UNDER CONTROLLED LABORATORY CONDITIONS

Chemical	*Conc. PPM Cation*	*Evaluations of Herbicidal Activity**							
		Pith.	*Naiad*	*Pondweed*	*Waterweed*	*Stargrass*	*Parrot-feather*	*Duckweed*	*Avg. Percent*
Diquat dibromide	0.255	50	100	93	100	87	100	100	90
Paraquat di(methyl sulfate)	0.228	47	100	87	100	100	97	100	90
Diquat + Paraquat	0.127 + 0.113	53	100	100	80	100	..	100	89
Diquat + Paraquat	0.172 + 0.075	80	100	100	93	100	..	100	96
Diquat + Paraquat	0.084 + 0.152	80	100	100	97	100	..	100	96
Diquat dibromide	0.51	63	100	100	100	100	100	100	95
Paraquat di(methyl sulfate)	0.456	87	100	83	100	100	97	100	95
Diquat + Paraquat	0.255 + 0.228	83	100	100	87	100	..	100	95
Diquat + Paraquat	0.343 + 0.150	80	100	100	97	100	..	100	96
Diquat + Paraquat	0.168 + 0.304	83	100	100	97	100	..	100	97
Diquat dibromide	1.02	73	100	97	100	100	100	100	96
Paraquat di(methyl sulfate)	0.912	83	100	100	100	100	100	100	97
Diquat + Paraquat	0.69 + 0.57	100	100	100	90	97	..	100	98
Diquat + Paraquat	0.86 + 0.37	80	100	100	83	97	..	100	93
Diquat + Paraquat	0.42 + 0.77	90	100	100	93	100	..	100	97
Control		20	30	31	20	20	26	23	24

* 0—No injury; 100—Complete kill.

Herbicidal evaluations on submersed aquatic weeds for both diquat and paraquat are given in Tables I and II. In comparison with approximately 1,500 other chemical compounds evaluated under the same conditions and on the same species of plants, these 2 compounds were among the 10 most herbicidally active. Results of herbicidal evaluations on emergent aquatic weeds of both diquat and paraquat are given in Table III. In comparison with approximately 650 other chemicals, these 2 compounds were the most herbicidally acive of the non-metallic chemicals.

These preliminary laboratory evaluation data, which in many instances were averages of 10 to 12 replications of a treatment rate, indicate a high degree of reproducible herbicidal activity for a development chemical. Thus, in addition to emphasizing the herbicidal potential of the two compounds, diquat and paraquat, it also demonstrated that the techniques developed were sound and gave reproducible results.

Toxicity to Fish

Techniques routinely employed to determine the toxicity of herbicides to several species of fresh-water fish, under controlled laboratory conditions, were used to study the toxicity of both diquat and paraquat (Lawrence, 1961a). Species of fish used in these tests included the following:

Bluegill, *Lepomis macrochirus*
Largemouth bass, *Micropterus salmoides*
Fathead minnow, *Pimephales promelas*
Channel catfish, *Ictalurus punctatus*
Rainbow trout, *Salmo gairdneri*

Toxicity tests were for 96 hours at 75° F. for the warm-water species, and at 65° F. for the trout. The fish used in these tests were from 1.5 to 2.5 inches total length.

The results of these tests indicated the following approximate threshold (LD_{10}) toxicity level for each species for 96-hour contact period.

Bluegill	9–10 ppm	Diquat	5 ppm	Paraquat
Largemouth bass	10 ppm	"	5 ppm	"
Fathead minnow	10 ppm	"	5 ppm	"
Channel catfish	10 ppm	"	5 ppm	"
Rainbow trout	5 ppm	"	5 ppm	"

When the minimum herbicidally active concentration (from laboratory tests) for each chemical is compared with its threshold toxicity to fish, it is immediately evident that at least a 10-fold safety margin exists.

Evaluations of Herbicidal Activity in Plastic Pools

Techniques developed at this Station to evaluate the herbicidal activity of chemicals to selected species of plants under simulated pond conditions in plastic pools were employed in this phase of the research on diquat and paraquat (Lawrence and Blackburn, 1962). The species of plants included in these pool experiments were as follows:

Pithophora sp.
Southern naiad
Waterweed (*Elodea densa*)
Pondweed (*P. diversifolius*)
Stargass
Alligatorweed
Water hyacinth
Duckweed
Parrotfeather
Waterfern (*Salvinia rotundifolia*)

The results of herbicidal evaluations on various species of aquatic weeds for diquat dibromide and paraquat di(methyl sulfate) are given in Table IV and for diquat dichloride and paraquat dichloride in Table V.

Observations were made on toxicity of these chemicals to fathead minnows and bluegills stocked in these treated plastic pools, and data on production of plankton and fish-food organisms during the experimental period were recorded.

TABLE II

AVERAGE EVALUATIONS OF HERBICIDAL ACTIVITY OF VARIOUS CONCENTRATIONS OF DIQUAT DICHLORIDE, PARAQUAT DICHLORIDE, AND MIXTURES OF THESE TWO CHEMICALS ON SEVERAL SPECIES OF AQUATIC PLANTS IN STILL WATER TESTS UNDER CONTROLLED LABORATORY CONDITIONS

Chemical	*Conc. PPM Cation*	*Evaluations of Herbicidal Activity**								
		Pith.	*Naiad*	*Pond-weed*	*Water-weed*	*Star-grass*	*Parrot-feather*	*Water-fern*	*Duck-weed*	*Avg. Percent*
Diquat dichloride	0.25	98	100	100	100	100	98	100	100	99
Paraquat dichloride	0.25	98	100	99	100	100	100	100	100	99
Diquat + Paraquat	0.125 + 0.125	90	100	100	100	100	97	100	100	98
Diquat + Paraquat	0.167 + 0.083	90	100	100	100	93	100	100	100	98
Diquat + Paraquat	0.083 + 0.167	83	100	77	97	100	83	100	100	92
Diquat dichloride	0.5	98	100	100	100	100	100	100	100	99
Paraquat dichloride	0.5	..	...	93	100	100	100	100	100	99
Diquat + Paraquat	0.25 + 0.25	90	100	100	100	100	100	100	100	98
Diquat + Paraquat	0.333 + 0.167	90	100	100	100	100	93	100	100	98
Diquat + Paraquat	0.167 + 0.333	100	100	83	90	100	87	100	100	95
Diquat dichloride	1.0	98	100	100	100	100	100	100	100	99
Paraquat dichloride	1.0	100	100	98	100	100	100	100	100	99
Diquat + Paraquat	0.5 + 0.5	100	100	100	100	100	100	100	100	100
Diquat + Paraquat	0.667 + 0.333	93	100	100	100	100	90	100	100	98
Diquat + Paraquat	0.333 + 0.667	100	100	100	100	100	100	100	100	100
Control	..	10	11	11	13	10	16	10	13	12

* 0—No injury; 100—Complete kill.

TABLE III

AVERAGE EVALUATIONS OF HERBICIDAL ACTIVITY OF VARIOUS CONCENTRATIONS OF DIQUAT DIBROMIDE AND PARAQUAT DI(METHYL SULFATE) ON SEVERAL SPECIES OF EMERGENT AQUATIC PLANTS IN STILL WATER TESTS UNDER CONTROLLED LABORATORY CONDITIONS

Chemical	*Conc. PPM Cation*	*Evaluation of Herbicidal Activity* *					
		Pith.	*Alligatorweed*	*Water Hyacinth*	*Stargrass*	*Duckweed*	*Percent*
Diquat dibromide	0	15	18	28	20	13	19
	2.55	62	100	100	100	95	91
	25.5	90	100	100	100	100	98
	51.0	100	100	100	100	100	100
Paraquat di(methyl sulfate)	2.28	95	100	95	100	100	98
	45.6	100	100	100	100	100	100

* 0—No injury; 100—Complete kill.

TABLE IV

AVERAGE EVALUATIONS OF HERBICIDAL ACTIVITY OF VARIOUS CONCENTRATIONS OF DIQUAT DIBROMIDE, PARAQUAT DI(METHYL SULFATE) AND MIXTURES OF DIQUAT AND PARAQUAT ON SEVERAL SPECIES OF AQUATIC WEEDS IN STILL WATER TESTS IN PLASTIC POOLS

Average Herbicidal Activity at Given Time Intervals Following Treatment*

	Control			*Diquat*† 0.5 ppm			*Diquat*† 1.0 ppm			*Paraquat*‡ 0.45 ppm			*Paraquat*‡ 0.91 ppm			*Diquat* + *Paraquat*‡ .25 + .23			— .33 + .67			— .67 + .33		
Plant	2wk.	2mo.	20mo.	2wk.	2mo.	20mo.	2wk.	2mo.	20mo.	2wk.	2mo.	7mo.	2wk.	2mo.	7mo.	2wk.	2mo.	7mo.	2wk.	2mo.	7mo.	2wk.	2mo.	7mo.
Alligatorweed	10	10	20	80	80	20	60	80	77	80	77	33	87	90	60	90	77	59	80	90	53	90	83	37
Water Hyacinth	20	20	..	80	100	100	90	100	100	87	100	100	93	100	100	87	100	100	90	100	100	87	100	100
Duckweed	30	30	..	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	..	..	..	..	..	..
Pondweed	20	30	35	100	100	47	90	100	77	40	60	47	40	43	30	83	70	43	47	33	17	70	43	73
Parrotfeather	13	17	..	..	..	..	..	..	..	73	73	100	100	100	100	90	100	100	..	..	..	..	..	..
Stargrass	30	30	25	90	100	100	90	80	100	83	100	100	90	100	100	..	100	100	..	.	..	..	..	..
Waterweed	30	30	35	100	100	100	90	100	100	60	80	100	80	100	100	90	100	100	90	100	100	90	100	80
Naiad	20	30	35	100	100	100	90	90	77	53	97	73	85	100	100	80	100	63	85	100	100	90	100	57
Pithophora	20	20	..	80	80	100	80	80	100	53	77	100	80	70	100	57	53	95	63	80	100	60	70	100
Chara	..	..	..	..	10	100	..	30	100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
AVERAGE	21	24	30	91	86	85	86	86	92	69	86	84	84	89	88	85	89	84	76	84	78	81	83	74

* 0—No injury; 100—Complete kill.
† Treatments were applied August 16, 1960.
‡ Treatments were applied October 24, 1961.

TABLE V

AVERAGE EVALUATIONS OF HERBICIDAL ACTIVITY OF VARIOUS CONCENTRATIONS OF DIQUAT DIBROMIDE, PARAQUAT DICHLORIDE, AND A MIXTURE OF THESE TWO CHEMICALS ON SEVERAL SPECIES OF AQUATIC WEEDS IN STILL WATER TESTS IN PLASTIC POOLS

	Average Evaluation of Herbicidal Activity at Given Time Intervals Following Treatment*																	
	Control			*Diquat*† 0.25 ppm			*Diquat*† 0.5 ppm			*Paraquat* 0.25 ppm			*Paraquat* 0.5 ppm			*Diquat* + *Paraquat* 0.125 + 0.15 ppm		
Plant	2 wk.	1 mo.	2 mo.	2 wk.	1 mo.	2 mo.	2 wk.	1 mo.	2 mo.	2 wk.	1 mo.	2 mo.	2 wk.	1 mo.	2 mo.	2 wk.	1 mo.	2 mo.
Alligatorweed	15	15	15	70	57	47	80	80	80	60	67	77	82	85	87	75	83	90
Water Hyacinth	15	15	30	80	90	100	90	90	100	55	63	90	90	97	100	72	77	100
Duckweed	20	20	32	90	85	55	95	90	77	90	87	80	90	80	77	92	95	97
Pondweed	20	20	20	87	95	47	90	100	100	87	67	52	92	100	65	90	95	30
Parrotfeather	17	17	10	77	65	50	90	90	52	90	87	95	87	85	100	82	75	70
Stargrass	15	15	15	90	100	100	90	100	100	90	100	100	90	100	100	90	100	100
Waterweed	15	15	20	90	95	100	90	100	100	90	87	100	90	90	100	90	97	100
Naiad	17	17	20	90	97	100	90	100	100	90	93	100	92	100	100	90	100	100
Pithophora	10	10	20	77	85	87	75	90	90	70	75	87	80	85	92	77	85	90
Vallisnera	15	15	12	90	93	52	90	100	85	90	80	92	90	93	75	90	95	47
Waterfern	10	10	20	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
AVERAGE	15	15	20	86	87	76	90	95	90	83	82	88	89	92	91	86	91	81

* 0—No injury; 100—Complete kill.
† All treatments were applied July 2, 1962.

From these results it was evident that both salts of diquat and of paraquat were very effective herbicides on a majority of the plants included in the experiment. There was no evidence of any toxicity to fish at the concentrations used. Furthermore, there was no evidence that either the diquat or paraquat salts interfered with plankton or fish-food organism production at concentrations up to 0.5 ppm of the cations.

Evaluations of Pond Treatments with Diquat and Paraquat

I. Barnyard grass (*Echinochloa crusgalli*)—Two 0.25-acre ponds infested with barnyard grass were used. One pond was treated with 2 ppm diquat dibromide salt (1.02 ppm cation) at 3 p. m. on June 5, 1961. No effort was made to cover the emergent vegetation, but an effort was made to obtain a fairly uniform distribution over the water surface. There was no detectable decrease in plankton production following this treatment. Neither was there a decrease in fish-food organisms. Rather, a very heavy population of chaoborus larvae were found after the grass began to die and decay.

The other pond was treated with 1 ppm diquat dibromide at 9 a. m. on June 6, 1961. An addition of 0.1 percent dynawet was made to this spray solution and an attempt was made to cover all emergent portions of the barnyard grass when applying this mixture. The immediate result was a browning of the sprayed portion of each plant, followed by an apparent regrowth of emergent seed stalks. There was a decided increase in the abundance of chaoborus larvae in the pond waters following the decay of grass leaves.

Within 6 weeks the barnyard grass and every other emergent type plant were eliminated from these two ponds, and they remained clear of weeds for the remainder of the summer and fall of that year. No evidence of interference with production of fingerling channel catfish was noted.

II. Net alga (*Hydrodictyon* sp.)—An 0.8-acre (average depth 3 feet) golden shiner brood pond at Tuscaloosa, Alabama was treated with 1 gallon of diquat dibromide (0.3 ppm diquat cation) on April 22, 1962. Within 3 days this pond was completely cleared of this net alga with no apparent effect upon the young shiners.

III. *Spirogyra* spp.—A 1-acre largemouth bass brood pond was treated with 1 gallon of diquat dibromide (approximately 0.2 ppm diquat cation) at 4 p. m. on May 11, 1962. Four days later the pond was seined to remove fingerling bass and no filamentous algae was present. A dense growth of wool grass (*Scirpus eriophorum*) in the upper end of this pond was also greatly reduced as a result of this treatment. Only a slight regrowth of filamentous algae appeared in this pond before it was drained in July, 1962.

Another 0.5-acre bass brood pond that had a moderate infestation of *Spirogyra* spp. was treated with 0.5 gallon of paraquat di(methyl sulfate) (approximately 0.5 ppm paraquat cation) at 5 p. m on May 11, 1962. Four days later this pond was seined to remove fingerling bass and no filamentous algae were present. No regrowth of filamentous algae had occurred in this pond by June 15, 1962 when it was drained.

IV. *Bacopa rotundifolia*—A 0.05-acre pond that had a complete surface covering of this plant was sprayed with a water solution containing paraquat dichloride (1 gallon per acre) and dynawet (1 pint per gallon of paraquat) at 4 p. m. on June 26, 1962. Within 10 days following this treatment all of these plants were dead and had sunk to the bottom of the pond. This pond was drained 2 weeks after it had been treated and was left dry for remainder of summer. A slight regrowth of *B. rotundifolia* appeared within a month following draining.

V. Pondweed (*Potamogeton diversifolius*)—A 0.25-acre catfish rearing pond that was heavily infested with this pondweed was treated with 0.25 ppm diquat dibromide plus 0.25 ppm paraquat di(methyl sulfate) on April 22, 1962. These weeds were killed and sank to the bottom so that the fish could be seined from the pond within one week following treatment.

In each of the above mentioned ponds, there was an increase in abundance of phytoplankton following the death and decomposition of treated weeds. No indications of detrimental effects upon the fish present in these treated ponds were noted.

SUMMARY

The chemical and physical properties and phytocidal activities of diquat (1:1'-ethylene-2:2'-bipyridylium cation) and paraquat (1:1'-dimethyl-4:4'-bipyridylium cation) are discussed.

Data on evaluations of herbicidal activity from controlled laboratory and plastic pool experiments indicate there was no difference in herbicidal effects of the various salts of these 2 quaternary bipyridyls on the aquatic species under observation. The results indicate that many submersed as well as emergent species of aquatic plants may be controlled for several weeks to several months by 0.2 to 0.5 ppm cation concentration of either diquat or paraquat.

Diquat appears to be safe to many fresh-water fishes at concentrations up to 10 ppm cation, and paraquat appears safe to many fishes at concentrations greater than 5 ppm cation.

Observations made in plastic pools and ponds treated with 0.5 ppm diquat or paraquat cation have indicated no harmful effects upon the fish or fish-food organisms from these herbicides.

From 80 to 100 percent kill of 15 species of aquatic weeds present in the pools and ponds has been obtained by a concentration of 0.5 ppm or less cation of either diquat or paraquat.

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STATUS OF Tilapia Nilotica LINNAEUS IN FLORIDA

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ABSTRACT

The Florida Game and Fresh Water Fish Commission's Fishery Division obtained 3,000 *Tilapia nilotica* fingerlings from Auburn University on August 30, 1961. These were used as brood fish and were stocked in a 3-acre naturally fertile mined-out phosphate pit in Central Florida at the rate of 1,000 per acre. From time of stocking until May, 1962, there was an estimated 7 inches of growth. During the latter part of May this pond appeared to go into an overcrowded condition. Twelve ponds totaling 65 acres have been stocked with tilapia from the brood pond. Stocking rates have varied from 2 adults to 1,000 fingerlings per acre. Minimum water temperature at the blood pit last winter was 53°F. Apparently no mortality occurred from this cold. It was estimated that 1,810 pounds of tilapia were produced per acre in the brood pit during a 369 day period. The fish were not fed and the pond was not fertilized. Tagging results to date from 100 bluegill and 100 tilapia show a return of 23 tilapia and 21 bluegills. The tilapia is thought to have great potential value in Florida as a sport and food fish.

INTRODUCTION

The exotic cichlid, *Tilapia nilotica* (Nile tilapia) was brought to Auburn University by S. Tal from Israel in 1957. Experiments were conducted at the