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Chemical Control of Submersed Waterweeds in Western Irrigation and Drainage Canals

Joint Report

Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

Bureau of Reclamation
U.S. DEPARTMENT OF THE INTERIOR

SUMMARY OF RECOMMENDATIONS

I. Control of rooted submersed weeds

1. Grade B xylene or other aromatic solvents (meeting Bureau of Reclamation specifications).

   a. *Emulsifiers*--certain anionic-nonionic blends at 1 to 1½% of aromatic solvent by volume.
   b. *Rate*--10 gal./c.f.s. or 10 gal./ft. of canal width, whichever is greater.
   c. *Period of application*--30 to 60 minutes.
   d. *Time of application*--when waterweeds begin impeding waterflow and before weeds reach the water surface at normal operating level.
   e. *Application equipment*--any sprayer that delivers a sufficient volume of chemical below the water surface at a pressure of 50 to 400 p.s.i. High pressures are best, although treatment at low pressures may be satisfactory.
   f. *Distance of control*--depends on density of weed growth and other factors--up to 6 miles.
   g. *Application intervals*--make "booster" treatments every 2.5 to 3 miles below point of initial treatment. Use 5 gal./c.f.s. if applied directly on top of treated "blanket" from initial treatment.
   h. *Frequency of treatment*--as needed during irrigation season, usually every 6 to 8 weeks.
   i. *Precautions*--use same care as in handling gasoline. Treated water not toxic to humans, farm animals, or wildlife, or irrigated crops when chemical used as recommended. Treated water highly toxic to fish and other aquatic fauna. Prevent treated water from entering fishing waters.

2. Acrolein *(available from and applied only by licensed dealers).*

   a. *Rate*--depends on density of weeds, water temperature, length of canal, and other factors--1 to 3 gal./c.f.s.
   b. *Period of application*--1¼ to 4 hours.
   c. *Time of application*--same as for aromatic solvents.
   d. *Distance of control*--depends on size of canal, density of weed growth, and other factors--5 to 20 miles.
   e. *Frequency of treatment*--as needed during the irrigation season, usually every 6 to 8 weeks.
   f. *Precautions*--acrolein is extremely irritating to eyes and nasal passages. Avoid contact with skin or breathing fumes. Water containing not more than 15 ppmv is not harmful to irrigated crops and water treated according to recommendations is not dangerous to humans, farm animals, or wildlife. Treated water kills fish and other aquatic fauna. Prevent treated water from entering fishing waters.

II. Control of algae

1. Filamentous algae, other than chara.

   a. *Chemical*--copper sulfate.
   b. *Rate*--1/3 to 2 lb/c.f.s.
   c. *Method of application*--place in coarse mesh bags and hang in stream or shovel crystals into water over concrete apron.
   d. *Frequency of treatment*--as needed during the irrigation season, usually every 10 to 14 days.
   e. *Distance of control*--depends on density of algal growth and hardness of water--2 to 10 miles or more.

2. Chara.

   a. *Chemical*--copper sulfate.
   b. *Rate*--2 to 4 lb/c.f.s.
   c. *Method of application*--same as for filamentous algae
   d. *Frequency of treatment*--as necessary for adequate control.

3. *Precautions*--wash hands thoroughly after handling crystals. Water treated as recommended not toxic to humans, farm animals, or wildlife, but may kill fish.

CONTENTS

CHEMICAL CONTROL OF SUBMERSED WATERWEEDS IN WESTERN IRRIGATION AND DRAINAGE CANALS[1]

Adequate delivery of irrigation water to millions of acres of irrigated farmlands each year depends on the timely control or removal of submersed weeds infesting irrigation systems. Dense stands of waterweeds seriously impede the flow of water in irrigation channels, which, in turn, causes other serious problems for the canal operator and farmer.[2] The impeded waterflow naturally raises the water level in the canal and thereby causes increased seepage and evaporation. In severe cases, canal banks are broken. Waterweeds also cause irregular silt depositions and the plant fragments clog weirs, sprinkler heads, and suction filters on irrigation pumps.

The most troublesome waterweeds in irrigation canals in the West are sago pondweed (Potamogeton pectinatus L.), horned pondweed (Zannichellia palustris L.), leafy pondweed (P. foliosus Raf.), Richardson pondweed (P. richardsonii (Ar. Benn.) Rydb.), American pondweed (P. nodosus Poir.), American elodea (Elodea canadensis Michx.), and several filamentous algae (Figures 1 and 2).

Figure 1.--A, American Pondweed *(Potamogeton nodosus Poir)*; B, sago pondweed *(P. pectinatus L.)*; C, Richardson pondweed *(P. richardsonii (Ar. Benn.) Rydb.)*.

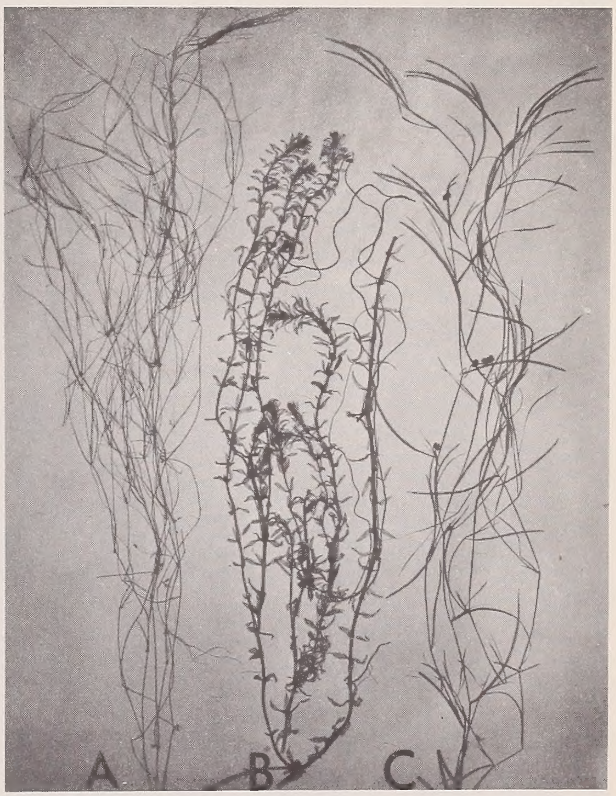

Figure 2.--A, horned pondweed *(Zannichellia palustris L.)*; B, American elodea *(Elodea canadensis Michx.)*; C, leafy pondweed *(Potamogeton foliosus Raf.)*.

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[1] Based upon laboratory and field research by the Agricultural Research Service and the Bureau of Reclamation. Assembled by R. D. Comes, Agricultural Research Service. Research information provided also by R. R. Yeo, V. F. Bruns, J. M. Hodgson, F. L. Timmons, and L. W. Weldon, Agricultural Research Service; T. R. Bartley, W. D. Boyle, N. E. Otto, and D. D. Suggs, Bureau of Reclamation.

[2] F. L. Timmons. Weed Control in Western Irrigation Systems. Losses Caused by Weeds, Costs and Benefits of Weed Control. U.S. Dept. of Agr., Agr. Res. Serv. ARS 34-14, September 1960. Joint Report, Agricultural Research Service, U.S. Department of Agriculture, and Bureau of Reclamation, U.S. Department of Interior.

Curlyleaf pondweed (P. crispus L.), water stargrass (Heteranthera dubia (Jacq.) MacM.), and waterplantain (Alisma gramineum (Torr.) Sam. var. Geyeri) are problem weeds in canals in some areas. Most of these waterweeds are rooted in the soil at the bottom and sides of irrigation channels and grow almost entirely beneath the water surface (Fig. 3). They are commonly referred to as moss or horsetail moss.

Figure 3.--A dense stand of waterweeds, primarily sago pondweed, growing in a section of lined canal on the Gila Project in Nevada. Deposition of sand and silt on top of the lining provided an ideal seedbed and anchorage for the waterweeds. (Photo courtesy Bureau of Reclamation, Region 3.)

Draining and drying, mechanical dragging, and handcleaning have been used extensively to remove waterweeds from canals. Draining and drying is often the most economical method if the water can be spared from irrigation and other uses for a period sufficient to dry the weed growth in the canal bottom. However, if an uneven bottom prevents complete canal drainage, results are usually unsatisfactory.

Since 1949, the use of chemicals to control waterweeds has increased steadily. Aromatic solvents, including xylol-type and chlorinated benzenes, were the only effective chemicals available for the control of rooted waterweeds until 1959-60, when acrolein (acrylaldehyde) was developed as an aquatic herbicide. Copper sulfate has been used successfully for many years to control most algal species.

The purpose of this publication is to provide canal operators and farmers with current information on the use of chemicals for control of submersed waterweeds in irrigation and drainage canals. Recommendations are based on field and laboratory research and on observations of many field applications of aromatic solvents for more than 10 years and of acrolein for 4 years.

CHEMICAL VERSUS MECHANICAL CONTROL METHODS

The use of aromatic solvents and acrolein usually has been limited to canals with not more than 100 cubic feet of waterflow per second (c.f.s.).[3] The limitation is not directly affected by the capacity of a canal but by the fact that the quantity of chemical required is directly proportional to the amount of waterflow. Therefore, treatment of large canals is expensive. However, chemical treatment of canals carrying 200 to 300 c.f.s. is practical and feasible when a large part of the water is used for sprinkler irrigation. Floating plant fragments and silty water caused by use of mechanical devices plug sprinkler systems; whereas, no silt is disturbed and the amount of floating plant material is greatly minimized when chemicals are used.

Mechanical methods of controlling submersed waterweeds usually are used in canals with waterflows too large to treat economically with chemicals. Bureau of Reclamation personnel[4] compared chain drag treatments, the most widely used mechanical method of controlling submersed waterweeds, and aromatic solvent treatments on eight irrigation projects in the Columbia Basin. They found that the cost of chaining ranged from $4.50 to $70 per pass per mile, or an annual cost of $45 to $675 per mile among channels of 50 to 3,700 c.f.s. capacity. An average of 10 passes per channel were required each year. The costs of aromatic solvent treatments ranged from $35 to $197 per mile for the year on channels of 8 to 40 c.f.s. capacity. Some benefits from chaining in addition to the removal of waterweeds were observed. Most managers contended that chaining reduced water losses and damage from seepage by sealing the canals. Destruction of bank weeds, smoothing of the berm at the waterline, and general reshaping of the wetted perimeter of the canal were also accomplished on certain canals during the chaining operation.

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[3] 1 c.f.s. equals 50 miner's inches in Wyoming, California, Idaho, New Mexico, and Utah. It equals 40 miner's inches in Arizona, Montana, Nevada, and Oregon.

[4] W. Dean Boyle and Delbert D. Suggs. Pondweed Control, Chaining vs. Aromatic Solvents. Region 1, Bur. Reclam. Spec. Rpt.

Aromatic Solvents

Aromatic solvents are mixtures of cyclic hydrocarbons of either petroleum or coal tar origin. Therefore, many different mixtures are available. However, the most effective xylol-type aromatic solvents for controlling submersed waterweeds meet the following specifications: [5]

Flash point (Tag closed cup), not less than	°F	80
Distillation range ASTM (D 86-54 °F at 760 mm. pressure):		
Initial boiling point, not less than		240
Not more than 10 percent, at		265
Not less than 50 percent, at		320
Not less than 90 percent, at		380
End point, not higher than		420
Aromatics, ASTM (D1319-55-T), not less than	percent	85
Water Content, not greater than	percent	0.2

Aromatic solvents that meet these specifications are available from many major distributors of pesticides or from distributors of petroleum or coal tar products. Aromatic solvents sold as aquatic weedkillers under various trade names should be purchased from reliable sources because the labels usually do not contain specifications.

A number of Bureau of Reclamation projects and many large private irrigation districts or groups of smaller districts purchased grade B xylene that meets Bureau of Reclamation specifications in bulk quantities. These specifications are:

Flash point (Tag closed cup), not less than	°F	75
Distillation range (°F at 760 mm. pressure):		
Initial boiling point, not less than		253
Not more than 5 percent by volume, below		266
Not less than 90 percent by volume, below		293
Dry point, not more than		311
Specific gravity at 60°/60° F, not less than		0.850
not more than		0.870

Adequate bulk storage (Fig. 4) is usually essential for such purchases to be practicable. When grade B xylene is purchased in bulk quantities and transferred from one tank or other vessel to another, care should be taken to insure that all containers are tightly closed and transfer units are free of water. Inasmuch as grade B xylene is a type of aromatic solvent, only the term aromatic solvent is used hereafter.

Emulsifiers for Aromatic Solvents

Aromatic solvents are insoluble in water and float on the water surface until evaporated unless an appropriate emulsifier is added. The purpose of the emulsifier is to form a good emulsion of the solvent throughout the water in the canal.

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[5] Developed and revised by the United States Bureau of Reclamation Laboratories, Denver, Colo., in 1958.

Figure 4.--Equipment for storage and application of grade B xylene or other aromatic solvents, consisting of 8,000-gallon storage tank, field tank, and 2-inch centrifugal pump; the latter two are skid-mounded. (Courtesy Bureau of Reclamation Region 1.)

Certain anionic-nonionic blend emulsifiers[6] at 1 to $1\frac{1}{2}$ percent by volume of aromatic solvent provide excellent emulsions. As much as 2 percent emulsifier may be needed in small canals that are heavily infested with waterweeds. The emulsifier must be thoroughly mixed with the aromatic solvent before the solvent is applied. Mixing may be accomplished by agitating the solvent while the emulsifier is added. The importance of proper emulsifier, concentration, and thorough mixing for satisfactory control of submersed waterweeds cannot be overstressed.

Aromatic solvents sold under various trade names as aquatic weedkillers usually contain sufficient emulsifier. However, if possible, the kind and percentage of emulsifier in the product should be ascertained prior to purchase.

Rate of Application

An aromatic solvent that contains 1 to $1\frac{1}{2}$ percent emulsifier by volume should be applied at the rate of 10 gallons per c.f.s. of waterflow or per 1-foot width of canal, whichever totals the greatest quantity of aromatic solvent for the treatment. Thus, if a canal is 15 feet wide and the waterflow is 10 c.f.s., a total of 150 gallons of aromatic solvent should be applied; whereas, if a canal of the same width has a waterflow of 20 c.f.s., 200 gallons of aromatic solvent should be applied. In channels where the weed infestation extends for no more than three-quarters of a mile, 6 to 8 gallons of aromatic solvent per c.f.s. of waterflow are sufficient to control waterweeds.

[6] Three of several emulsifiers that have been widely tested appear about equally satisfactory. Information concerning names and manufacturers of recommended emulsifiers may be obtained from any of the authors or from local Bureau of Reclamation offices.

These lower rates will control certain species of waterweeds for longer distances but frequently result in an increase of more resistant species. The total amount of aromatic solvent should be injected into the water during a period of 30 to 60 minutes.

Canals more than 3 or 4 miles long that contain moderate to dense infestations of waterweeds usually require supplemental or "booster" treatments to maintain a toxic concentration of aromatic solvent. The distance downstream at which booster treatments should be applied varies from canal to canal; each operator has to determine the most advantageous interval for a given canal. However, in most instances, intervals of 2.5 to 3 miles have been satisfactory and are recommended. Because a part of the original application of solvent remains in emulsion after moving 2.5 to 3 miles down the canal, booster treatments should be applied at a rate of 5 gallons of solvent per c.f.s. of waterflow. The booster treatment should be started as soon as the emulsion or "blanket" of previously treated water arrives at the booster station. Otherwise, the full rate of 10 gallons per c.f.s. would be necessary.

Less aromatic solvent is required if the waterflow in the canal can be reduced during the treatment. However, the weeds should be completely covered and water should be moving through them during the treatment. Flows should never be reduced to the extent that weed growth is compacted on the water surface. Proper timing of the treatment will allow the flow to be reduced and still result in effective weed control.

Time of Application

The aromatic solvent should be applied as soon as waterweeds begin to interfere noticeably with normal delivery of water and before plants reach the water surface. Excellent temporary control is obtained when treatments are applied at an earlier growth stage, but regrowth is rapid and retreatments are required within a short time. Treatments applied after the plants have matted at the water surface are usually less effective because the compacted weed growth forces the main current to pass over or channel around the mats of waterweeds and prevents proper distribution of the emulsion (Fig. 5).

Figure 5.--Matted waterweed growth prevents the proper distribution of an aromatic solvent emulsion.

Various types of centrifugal, diaphragm, gear, or piston pumps have been used successfully to introduce the aromatic solvent into flowing water. Pumps considered for this purpose must be resistant to solvents and have adequate capacity and pressure. Pressures that range from 50 to 400 p.s.i. are satisfactory. Dispersion of chemicals in water and stability of emulsions are usually enhanced by high pressures. Minimum pump capacity would be 0.2 gallon per minute at 50 p.s.i. for each c.f.s. of waterflow encountered in the largest canal to be treated with the unit. Regardless of the type of unit, hoses, connections, and other parts in contact with the solvent must be oil resistant.

The aromatic solvent may be applied directly from the holding tank into the water through a low-volume unit with one or more small orifice nozzles or indirectly through a high-volume centrifugal pump with a single, large nozzle (Fig. 6). The solvent must be applied beneath the water surface. With a high-volume unit, water from the canal and the aromatic solvent from the holding tank are drawn into the pump bell through dual suction hoses, mixed thoroughly, and discharged under pressure into the stream. The flow of aromatic solvent usually is metered and may be regulated by a gate valve (Fig. 7). A detailed discussion and illustration of this method was published[7].

When the aromatic solvent is introduced into a channel by the direct method, application immediately above a weir, drop, or other structure with a moderately turbulent pool at the bottom helps to disperse the solvent. Applications with a high-volume centrifugal pump are not so dependent on water turbulence to establish a good emulsion. Other advantages of the indirect application method are: (1) clogging of small-orifice nozzles by foreign particles is eliminated, (2) positive mixing of water and solvent within the pump provides increased emulsion stability, and (3) channels with a wide range in capacities can be treated at the desired rate by simply adjusting the flow of solvent to the pump.

Figure 6.--A, A simple unit for introducing aromatic solvent that consists mainly of a small gasoline engine, a ½-inch gear pump, and a boom with fine spray nozzles. Note that the application is made just above a small drop. B, Water from the canal through a 4-inch hose and solvent from the supply tank via a calibration drum are drawn into the pump casing, and the mixture is discharged under pressure into the channel through a 2-inch hose with a fire-hose nozzle.

[7] V. F. Bruns. Pump Unit for Introducing Aromatic Solvents and Other Aquatic Weed Killers. U.S. Dept. Agr. Pub. ARS-31-1. 1956.

Figure 7.--Indicating flowmeters, simple in design and construction, made to specifications, and showing rate of flow in gallons per minute, have been more successful and trouble-free in applying aromatic solvents and other aquatic herbicides than register-type meters. (Photo courtesy Bureau of Reclamation Columbia Basin Proj ect.)

Calibration and Calculations

Accurate determination of waterflow in the channel immediately before treatment is essential to determine chemical requirements. Weirs, orifices, or similar devices give rather accurate measurements of waterflow. In the absence of such measuring devices, the approximate flow of water may be computed by measuring the cross-sectional area of the water (average depth x width) and the velocity of flow. A convenient and fairly accurate measurement of velocity of flow may be determined by placing a waterlogged stick, or other object that will settle slightly, in the water and measuring the time in seconds required for the object to travel a predetermined number of feet. Velocity measurement should be repeated at least 3 times. The object should be placed in the center of the channel. The velocity (feet per second) is equal to the distance traveled (feet) divided by the time (seconds). Use the average for the three trials. The volume of flow (c.f.s.) may then readily be estimated by use of the following formula:

Average width, in feet, x average depth, in feet, x velocity, in feet per second, x 0.9 = cubic feet per second.

The quantity of aromatic solvent to be introduced per minute to yield the necessary concentration may be calculated from the following formula:

$$\frac{\text{Waterflow c.f.s. x 10}}{\text{application time in minutes}} = \text{gallons of aromatic solvent needed per minute.}$$

Example: A canal with a waterflow of 30 c.f.s. is to be treated with aromatic solvent at the recommended rate of 10 gallons per c.f.s. over a period of 30 minutes.

$$\frac{30 \text{ c.f.s. x } 10 \text{ gal.}}{30 \text{ min.}} = 10 \text{ gallons per minute.}$$

Application equipment must be calibrated and adjusted to apply the correct quantity of aromatic solvent over a period of approximately 30 minutes.

A flow meter, assembled between the supply tank and pump, is an integral part of much of the equipment used in application of aromatic solvent. However, if a flow meter is lacking or broken, a "tank dip stick" calibrated for the aromatic solvent container and boldly marked in gallons is an economical and fairly accurate means of measuring the quantities of aromatic solvent as it is being applied. After measuring and recording the tank contents in gallons, the pump can be put in operation and the outlet valve set on an estimated opening.

After the number of gallons to be applied per minute is determined, the desired valve setting is gradually made through a series of trial settings at 1-minute intervals. With little familiarity and experience in operation of the equipment, operators establish the desired valve setting after two or three of these 1-minute trials.

Distance and Period of Effective Control

The distance waterweeds are controlled effectively by a single recommended application of an aromatic solvent averages 3 miles. Conditions of the water, water velocity, and waterweeds vary greatly among irrigation canals, and these conditions influence the effective distance of waterweed control. Under ideal conditions, control may be obtained for 6 miles.

Treatments with an aromatic solvent destroy directly only those parts of the plant contacted by the emulsion. One or two effective treatments with an aromatic solvent are usually sufficient to permit unimpeded flow of water through the channel during a major part of the season in the Intermountain States. However, three or more treatments may be necessary in areas with year-round or exceptionally long irrigation seasons. On the average, more than 75-percent control will be maintained for 6 weeks after each treatment.

Other Factors That May Affect Results

Weed species.--Weed species vary widely in their susceptibility to aromatic solvent. Horned pondweed and leafy pondweed are more susceptible than some of the other rooted waterweeds commonly found in western irrigation systems. Aromatic solvent has not been effective on waterplantain and should not be used in an attempt to control this species. Horned pondweed and leafy pondweed may be controlled with 8 gallons of aromatic solvent per c.f.s. of waterflow. However, if other less susceptible species are present in the canal, and they usually are, the less susceptible species will become dominant after successive solvent treatments over a period of years.

Density of Growth.--Aromatic solvents are most effective in canals where weed growth is evenly distributed and sparse or only moderately dense. However, excellent control of waterweeds can also be obtained in canals with dense, irregular stands if the treatment is applied before the weeds reach a mature stage of growth. The desirability of treating channels before weed growth becomes matted cannot be overemphasized.

Velocity of Flow.--The effectiveness of an aromatic solvent is influenced by the overall water velocity and by variations in flow caused by channel irregularities. The introduction time should be increased in canals with rapid flow. Good weed control has been obtained in slow-moving water but over a much shorter distance because of the gradual separation of the emulsion after a certain period of time. Optimum results have been obtained in canals with velocities of 0.50 to 1.25 feet per second.

Salt and Silt Content of Water.--Submersed aquatic weeds are generally inhibited in water that is continuously silty and may not create a problem under such circumstances. However, most irrigation waters are silt laden only intermittently and at a level insufficient to provide satisfactory control of water weeds.

Aromatic solvents are much less effective when applied in water with a high silt content, and treatments should be postponed under such conditions. A moderate to slight silt content does not affect results appreciably.

Emulsions of an aromatic solvent and water are also adversely affected if the water contains a high salt concentration. Treatments have been effective in waters that are neutral to moderately alkaline.

Water Temperature.--Water temperature does not seem to have any great effect on the aromatic solvent in controlling waterweeds, except as it indirectly affects stability of the emulsion. Good results have been obtained when water temperatures were as low as 58^{o} F. and as high as 88^{o} F. It is believed that results tend to be better when water temperatures are 70^{o} F. or higher.

Effect on Irrigated Crops

Water containing an aromatic solvent at the concentrations recommended for waterweed control (10 gallons per c.f.s. over a period of 30 to 60 minutes) may be used for furrow irrigation without injury to a wide variety of crop plants. Treated water may also be used for flood irrigation if most of the foliage of the crop plants is not submersed in the treated water. Leaves that are submersed in treated water may become yellow and die.

Crop plants that have been irrigated experimentally with water containing an aromatic solvent at the recommended rate without reducing yields include alfalfa, red Mexican beans, carrots, cotton, grain sorghum, Ladino whiteclover, lettuce, lima beans, wheat, oats, orchardgrass, potatoes, sugarbeets, and sweet corn.

Effect on Fish and Other Animals

Water containing an aromatic solvent is very toxic to fish and many other aquatic organisms. Fish, crayfish, snails, and various insects that come in contact with treated water are killed.

Treated water is distasteful and livestock usually refuse to drink it. Aromatic solvents have been used for many years in diversified farming areas, and no ill effects to livestock drinking the treated water have ever been reported.

Cost of Material

The cost of aromatic solvents and emulsifiers is extremely variable and depends on availability, quantity purchased, shipping charges, competition, and other factors. The price of ready-mixed materials usually range from $0.40 to $1.25 per gallon. When purchased separately, prices may range from $0.26 to $0.60 per gallon for the aromatic solvent and $2.25 to $4 per gallon for emulsifiers. Large irrigation projects usually purchase aromatic solvents in bulk quantities, ship the material in railroad tank cars or tanker trucks, and thus reduce the costs considerably. In recent years, several relatively small irrigation companies located in a given area have combined their orders for an aromatic solvent with the resulting advantage of purchasing in bulk quantities.

Precautions in Use

Aromatic solvents are highly flammable and should be handled with the same precautions that are used in handling gasoline and similar products. Do not inhale solvent fumes, and avoid prolonged contact of solvents with the skin.

Acrolein[8]

Treatments with acrolein for waterweed control are applied only by licensed applicators with specialized equipment and training. Licensed applicators usually cover rather wide geographical areas and are usually associated with large chemical distributors. If the licensed applicator for acrolein in a particular area is not known, contact the manufacturer or your nearest Bureau of Reclamation office for information.

A single treatment of acrolein applied at the proper time and at a rate of 2 to 3 gallons per c.f.s. of waterflow controls submersed waterweeds for a distance up to 5 miles in small channels and 20 miles in large canals.

Factors That May Affect Rates of Application and Results

Plant Characteristics.--All submersed waterweeds and algae commonly found in western irrigation channels, with the exception of waterplantain, are susceptible to acrolein. Treatments should be applied after the weed growth begins to interfere noticeably with normal waterflow, but before it becomes matted (same as for aromatic solvents). Although acrolein is water soluble, compacted weed growth prevents the free movement of treated water through the weeds and poor results may be obtained under such conditions.

Acrolein also destroys only those parts of the plants contacted, and regrowth occurs from the underground structures of rooted submersed waterweeds. Usually one or two acrolein treatments per season are sufficient to prevent excessive weed growth from accumulating in canals of the Intermountain States, but three or more treatments may be necessary in regions with long or year-round irrigation seasons.

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[8] Company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product listed by the USDA.

Water Characteristics.--Water temperature and velocity influence the herbicidal effectiveness of acrolein in irrigation channels. However, excellent waterweed control can be obtained under most conditions with the proper rate and duration of application.

Two to three gallons of acrolein per c.f.s. of waterflow are generally required when water temperatures are below 70° F., but 1 to 2 gallons per c.f.s. are usually sufficient when temperatures are above 70° F. The higher rates of application (2 to 3 gallons per c.f.s.) should also be used when water velocity exceeds 2.5 feet per second. In addition, the introduction time should be at least 2 hours when the velocity is greater than 2.5 feet per second. Under normal conditions, the introduction time may range from 1 1/4 to 4 hours without changing the effectiveness of the treatment.

Effect on Irrigated Crops

Many field and garden crops are rather sensitive to acrolein. However, crops may be flood-, furrow-, or sprinkler-irrigated with water containing acrolein not in excess of 15 parts per million by volume (p.p.m.v.) When concentrations of acrolein exceed 15 p.p.m.v., the water must be diverted into a reservoir, wasteway, or drain.

The concentration of acrolein in flowing water may be reduced by extending the introduction time. In many situations, however, it may be advantageous to use a short introduction time and to dispose of the treated water. Licensed applicators usually have equipment to determine acrolein concentrations in water.

Effect on Fish and Other Animals

Acrolein is highly toxic to warm-blooded mammals, fish, frogs, snails, crayfish, and other aquatic organisms. However, concentrations of acrolein needed to control submersed aquatic weeds are not toxic to farm animals. One investigation[9] gave lactating dairy cows acrolein in drinking water at levels of 30 and 60 p.p.m. for 24 hours with no adverse effects on body weight, water intake, feed and water consumption, or milk and butterfat production. The only noticeable effect on dairy cattle given acrolein in drinking water at a level of 90 p.p.m. for 24 hours was a one-fourth to one-third drop in water and hay consumption and a transitory drop in weight. Livestock are usually exposed to treated water for only a few hours. General field observations have indicated that livestock usually do not consume treated water.

Costs of Application

The cost of applying acrolein for control of submersed waterweeds varies from canal to canal and depends upon factors such as weed density, length and volume of canal, water temperature, velocity of flow, and distance from licensed applicator. In general, the total cost of applying acrolein ranges between $1 and $4 per c.f.s. of waterflow per mile of channel treated, but costs as low as $8 per c.f.s. with no limitation on mileage have been reported by large irrigation companies that have licensed applicators on their staffs and can purchase acrolein directly from the manufacturer.

Precautions

Acrolein, the common name for acrylaldehyde, is a highly reactive chemical. Vapors of acrolein severely irritate the eyes and respiratory passages; therefore, it is practically

[9] Aqualin Herbicide Process Handbook. Shell Chemical Corporation, 1959.

impossible to remain voluntarily in vapor-tainted atmosphere long enough to produce serious physiological effects. Acrolein must be handled with extreme caution. Acrolein drums should be opened only with adequate ventilation, preferably outdoors. All personnel should wear face shields, and a gas mask should be available for emergency use. Do not smoke near open drums. Since it is highly reactive, contamination with any foreign material must be avoided. It will react violently if it comes in contact with acids or alkalies.

Copper Sulfate[10]

Control of Filamentous Algae, Other Than Chara

Filamentous algae appear as slimy blankets, or mats, on the water surface or as long strings attached to objects below the water surface. They also adhere to concrete surfaces or rocks. They may float downstream and clog lateral headgates, suction screens, weed screens, and siphon tubes. Copper sulfate (blue-stones or blue vitriol) has been used extensively for many years to control various species of filamentous algae in irrigation channels.

Time and Frequency of Treatments

Copper sulfate treatments should be started within a week after water has been turned into a canal that has a past history of algal problems. If a canal has not been infested previously with algae, treatments should be initiated as soon as an infestation is noticed. Do not wait until filamentous algae becomes a serious problem before initiating a control program, as the build up of spores perpetuates the problem after treatment.

Single treatments with copper sulfate temporarily control most filamentous algae for distances of 2 to 10 miles, and effects 30 to 40 miles below the point of application have been reported in large canals. Algal density, organic matter content and hardness of the water, and the quantity of copper sulfate applied influence the linear distance that a single treatment is effective. Treatments must be repeated every 10 days to 2 weeks for maximum control.

Rate of Application

Factors that affect the distance down a canal that a single treatment of copper sulfate is effective also affect the rate of application. As little as one-third pound of copper sulfate per c.f.s. of waterflow has been effective in controlling filamentous algae in the Columbia Basin of Washington; whereas, 1 to 2 pounds per c.f.s. of waterflow are needed in many of the Rocky Mountain States and California. At the present time, it is necessary for each operator to determine the most efficient and economical rate of application for its particular channels. A rate of 2 pounds of copper sulfate per c.f.s. of waterflow, applied every 4 to 6 miles, is recommended for use in channels where the effectiveness of copper sulfate is not known. Adjustment of treatment rate and interval may be necessary after results of the previous treatments are known.

Method of Application

Treatments may be applied by placing the necessary quantity of copper sulfate crystals (1/2 to 3/4 inch in size) in nylon mesh or burlap bags and suspending them in the channel. The bags

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[10]Additional information provided by C. G. Graham, Glenn Berry, and Dean M. Schacterle, Bureau of Reclamation.

should be suspended in the flowing water with one-third to one-half of the copper sulfate crystals submerged. In some large canals satisfactory results have been obtained by shoveling the required amount of copper sulfate crystals into the water above a concrete apron.

Control of Chara

Chara (Stonewort) is a genus of algae that is anchored to the bottom soil and resembles rooted submersed aquatic plants. It is more difficult to control than other filamentous algae. When mashed and rolled between the fingers, it has a distinctive granular or sandy texture and a disagreeable odor. Chara usually is not a problem in fast-moving waters, but it may become a serious problem in sluggish waters. It can be controlled with copper sulfate at a rate of 2 to 4 pounds per c.f.s. of waterflow.

Effect on Fish and Other Animal Life

Concentrations of copper sulfate needed to control algae in flowing water may kill fish. However, copper sulfate is much less toxic to warm-blooded mammals than to fish, and consumption of water that contains concentrations of copper sulfate necessary to control algae does not injure livestock or humans.

Cost of Treatment

The use of copper sulfate is the most economical chemical method known for controlling algae. It retails for $16 to $22 per 100 pounds.

Other Chemicals

Numerous other chemicals have been tested in laboratory and field experiments, but most of them have proved ineffective or too expensive for general use. A few promising soil-applied herbicides are being evaluated, but these are not available for general use at this time.