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Weed Control Investigations On Some Important Aquatic Plants Which Impede Flow of Western Irrigation Water

United States Department of the Interior, Bureau of Reclamation

UNITED STATES
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WEED CONTROL INVESTIGATIONS ON SOME IMPORTANT AQUATIC PLANTS WHICH IMPEDE FLOW OF WESTERN IRRIGATION WATERS

JOINT REPORT

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Agricultural Research Service
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CONTENTS

CONTENTS--Continued

WEED CONTROL INVESTIGATIONS ON SOME IMPORTANT AQUATIC PLANTS WHICH IMPEDE FLOW OF WESTERN IRRIGATION WATERS*

E. T. Oborn, W. T. Moran, K. T. Greene, and T. R. Bartley**

INTRODUCTION

During the past 50 years, the acreage of land placed under irrigation in the western United States has increased greatly to meet the growing demand for food and fiber production. To provide this water for crop production, it is necessary not only for river waters to be impounded and irrigation canal distribution systems established but also for the irrigation waterways to be free of obstructing plant growths which impede the flow of water. This requires various types of weed control measures in order that originally designed carrying capacities of the waterways may be maintained. Methods involving new techniques developed mostly in the greenhouse and laboratory are suggested, which may make possible eradication or control with less expenditure of time, effort, and cost.

Several of the irrigation evils attendant upon the presence of channel and ditchbank weeds in and along open water distribution systems have been discussed in a publication by the Bureau of Reclamation (9)***. These include undesirable increases in the following: (a) ditchbank seepage and overflow, (b) evaporation from the additional water surface exposed, (c) silt deposition, (d) useless water consumption by weed transpiration and metabolism, (e) aggravation of soil alkali and seepage conditions on normally drained farms, (f) weed seed infestation on crop land, and (g) difficulty in ditch chaining and bank mowing due to presence of tree size weed growth. Field laboratory growth aspects of some of the troublesome aquatic weeds are shown in Figure 1.

For successful irrigation farming, it is essential that adequate water of suitable quality be available at the proper time and place

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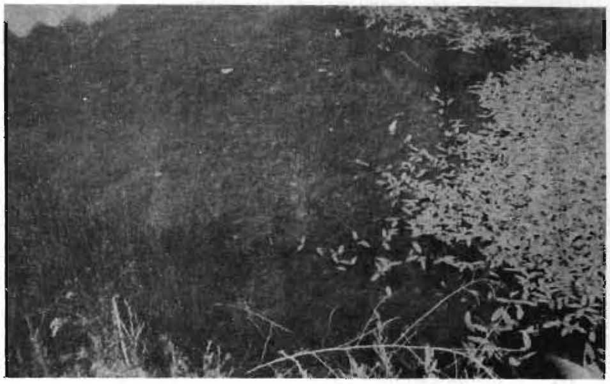
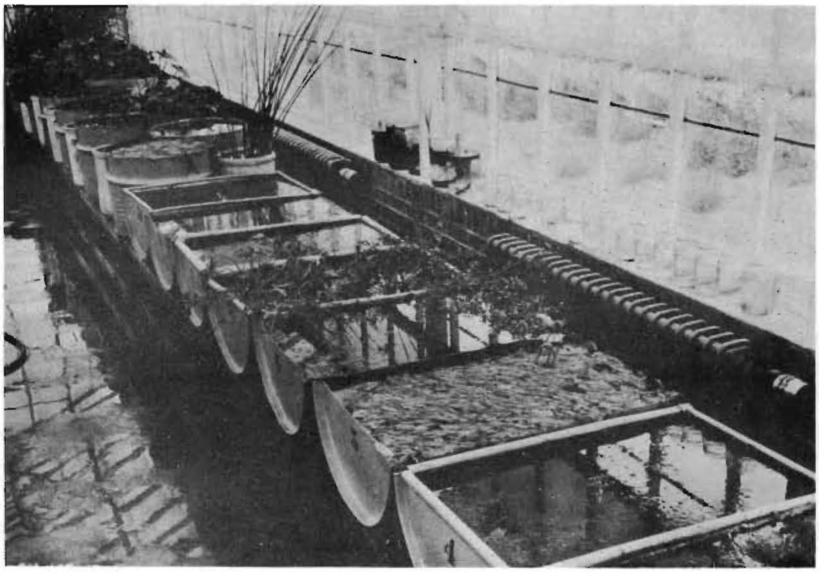
***Numbers in parentheses refer to publications which are listed under Bibliography, page 78.

A
Leafy pondweed in an irrigation ditch



B
Pondweeds in a lake, sago pondweed (left), American pondweed (right)



C
Greenhouse cultures of troublesome aquatic weeds

Fig. 1 Field and laboratory aspects of some of the troublesome waterweeds for crop production. A water shortage due to useless plant consumption or reduction in carrying capacity of a canal usually results in decreased crop quality, yield, or even a failure. Therefore, it is imperative to keep the waterways open and flowing with an adequate water supply.

REVIEW OF LITERATURE

It is believed that the following references have an important bearing on the work reported in this paper. Bartsch (5), Martin (44), Workman (93), Zimmerman (94), Crafts (13), Speirs (80), McMullin et al (49), and the Bureau of Reclamation (9) have discussed the several methods used in the past in the attempt to keep waterways open and water storage basins free of plant growths. Among these are chaining, draining, dredging, burning, biological control, and chemical control. None of these has been completely satisfactory or generally permanent because the roots, rhizomes, or other propagules of the treated aquatic vascular plants have not been killed.

Eicher (19) found that in Arizona, when the aniline dye, nigrosine, was used, semi-emergent aquatic weeds failed to reach the water surface.

Smith and Swingle (79) reported the successful use of commercial fertilizer to control Najas guadalupensis, Potamogeton pusillus, P. angustifolius and Chara sp. They applied 100 pounds of 6-8-4(percentage of nitrogen, phosphorus and potassium, respectively) and 10 pounds of sodium nitrate per acre at each application, making the first application in the winter and others at monthly intervals and broadcasting the fertilizer over the weed-infested portion of the pond. Algae growing as a result of the increased fertilization shaded the vascular weeds and Chara so that they became detached and floated in large decaying masses. They found that most of the weeds and filamentous algae disappeared by the latter part of June.

Jackson (38) believes that application of commercial fertilizer is the safest and best method for controlling submersed weeds in many ponds. He observed that waterweeds exposed on the mud cannot be expected to die even after several days of exposure. He observed further that even exposure for several weeks in the summer did not kill out some of the aquatic plants.

While Pond (66) concluded that rooted aquatic plants and phytoplankton were not in direct competition with each other since aquatic plants draw nutrients chiefly from the soil, Hasler and Jones (33) observed that dense growth of large aquatic plants, in small experimental silo-ponds, had a statistically significant inhibiting effect upon phyto- and rotifer plankton. Crustacea plankton did not appear to be affected.

Ward and Whipple (87) believed that calcite coatings are not firmly fastened to the leaf and may be easily scaled off or loosened by bending the leaf. They report the presence of the coatings seems to make little difference to the plant, as the tissue beneath appears a healthy green color though frequently of more delicate tint than the unincrusted areas of the leaf.

Levardsen (42) found that balanced mixtures of orthodichlorobenzene-xylene and trichlorobenzene-xylene in the proportions of 3 to 1 or 2 to 1, by volume, were effective in the control of submersed weeds. The emulsified, balanced mixture remained longer in contact with the submersed plants than did any of the components separately.

Seale, Randolph, and Stephens (74) observed that of three aromatic solvents evaluated as herbicides on water naiad, Najas guadalupensis, the one with initial boiling point of 281° F and final boiling point of 344° F applied at the rate of about 250-350 ppm was most effective in causing dense growth of water naiad to sink to the bottom of the treated ditch and commence disintegrating a short time after treatment, thus permitting a free movement of water in an open channel. It should be noted that these boiling points approximate those for industrial xylene, i.e., initial boiling point 266° F and final boiling point 302° F.

Dunk and Tisdall (17) found that either the rate of water flow or the temperature or both appeared to play an important part in the results obtained when aromatic emulsions of petroleum naphtha and chlorinated benzene were mixed with flowing water at the rate of 600 ppm for 60 minutes.

Evans, Mitchell, and Heinen (20), Rasmussen (67), and Smith, Hamner, and Carlson (78) have shown that phenoxyacetic acid derivatives in herbicidal concentrations stimulate plant respiration, food digestion, and utilization of reserve food materials.

Freeland (27) observed that 2,4-D (2,4-dichlorophenoxyacetic acid) at concentrations of 30 and 100 ppm decreased the rate of photosynthesis in true waterweed (Anacharis canadensis) with the higher concentration being more effective.

Mitchell and Brown (52) treated morning-glory (Ipomoea lacunosa) plants with 2,4-D in herbicidal concentrations and found a depletion of readily available carbohydrates within 3 weeks after treatment.

Chao (10) in a study to investigate the phytotoxic action of 2,4-dichlorophenoxyacetic acid on duck weed (Lemna minor) and water fern (Salvinia rotundifolia) found that fuel oil and tributyl phosphate, normal carriers for 2,4-D esters, were lethal to duck weed in concentrations as low as 0.3 percent. He pointed out that of the various commercially available formulations of 2,4-D, the effectiveness, in decreasing order, was as follows: (a) acid, (b) ester, (c) amine salt, and (d) sodium and ammonium salts.

Van Overbeek, Blondeau, and Horne (85) believed that in the range of herbicidal effects one undissociated molecule of 2, 4-D will do the work of 1 million or more undissociated molecules of the native plant auxin indoleacetic acid.

Hall and Hess (31) have suggested that the relatively high tolerance of submersed aquatics to 2, 4-D is associated with their reduced vascular systems and resulting limited transport of phenoxyacetic acid derivatives.

So far as is known, Surber, Minarik, and Ennis (82) are the only workers who have controlled normally submersed aquatic plants by first draining off the water and then spraying the flaccid, rooted aquatic plants lying on the soil bottom with systemic herbicides. A pond with American pondweed (Potamogeton nodosus) was drained and the bottom sprayed with 2, 4-D dissolved in tributyl phosphate at the rate of 10 pounds 2, 4-D acid equivalent per acre. American pondweed shoots failed to reappear after this herbicidal treatment.

Jones and Andrews (39) used the sodium salts of 2-methyl, 4-chlorophenoxyacetic acid and 2, 4-dichlorophenoxyacetic acid each as a dust with a lime diluent and found in small scale field experiments that concentrations of 10 ppm in treated stagnant water killed most of the angiospermous waterweeds found in Sudan Gezira.

Steenis (81) emphasized the need of making herbicidal applications, systemic or nonsystemic, at optimum stages of plant growth and environmental conditions in order that maximum shock to the treated plant might be effected with a given treatment. Time of fruiting for nonsystemic herbicides and active vegetative growth and foliage development for systemic herbicides were considered as optimum times for applications.

Hitchcock et al (35) cleared water hyacinth (Eichornia crassipes) and alligator weed (Alternanthera philoxeroides) infested areas by applying 2, 4-D at 8 pounds per acre. The initial spray was followed by a second patrol maintenance spray to insure complete eradication.

Tukey et al (84) studied responses and correlated histological changes of bindweed and sow thistle plants treated with aqueous sprays of 2, 4-D acid at 1000 ppm in 0.5 percent Carbowax 1500, applied during midsummer while the plants were growing vigorously. It was found in part that in treated plants pollen grains and leaf cells were plasmolyzed, flower development was arrested, chlorophyll formation was checked and cell division was activated in vascular bundles of leaves. Cell division was increased in the cambial zones and phloem regions of stem and rhizome and cortical cells were greatly enlarged and frequently torn. While starch hydrolysis was inhibited "in vitro" by the action of the 2, 4-D acid, disappearance of starch from the endodermis of stem and inner cortex of rhizome and root was correlated with active cell division in the phloem region of those portions of the plant.

Watson (88) found that the numbers of bacteria in bottom samples from lakes decreased by the presence of residual copper from copper sulfate weed treatment applied 2 years prior to the sampling. The inhibition which occurred in the presence of a large amount of organic matter apparently was caused by concentrations in the range of 11 to 30 ppm total copper. Much higher counts were observed in controls containing 4 to 7 ppm copper and low organic matter content.

Henkelekian and Crosby (34) eliminated interfering material growing in the San Diego aqueduct and restored original flow by application of 3.5 to 4 ppm chlorine to the water. They maintained flow capacity by application of a chlorine dosage of 2 to 3 ppm for a period of 2 hours once a week.

McGaha (48) concluded that of 61 species of insects studied 58 were either phytophagous or under certain conditions used tissues of hydrophytes as food. Hydrophyte injury included inserting eggs and respiratory spines into plant tissues; sucking of juices from leaves; using leaves for case making; and consuming various plant parts as food. McGaha found too that some insect species are intimately, and in some instances obligatorily, dependent on the plants.

Nikiforov and Morozova (59) found that nutria (Myopotamus coypus), a South American aquatic, beaver-like rodent readily eats macrophytic water vegetation in amounts up to 100 kilograms of green foliage over a 30-day period.

When Anderson (1) made a semiquantitative survey of aquatic vegetation in the growing seasons immediately prior to and following the removal of carp, he found the spread of Chara vulgaris over almost the entire lake bottom was by far the greatest change in abundance of any plant species. Potamogeton pectinatus and Vallisneria americana also made significant increases in abundance.

Matheson (45) reached the conclusion that Chara fragilis in some way prevented the development of mosquito larvae. He found that where Chara maintained a vigorous growth no oviposition took place.

Crocker (14) found that seeds of water plants may be kept for years without germinating in water that is free from fermentation. Fermentation in the water stimulated germination.

Muenscher (58) obtained results of germination tests made on 43 species of aquatic plants which indicated that storage in water at a temperature just above freezing is the best of the treatments applied to insure viability and quick germination in most of the species tested. He found too that storage in water at room temperature, dry storage at 1-3° C., or at room temperature prohibited germination of aquatic seeds.

McAtee (46) discussed the methods of propagation of eleven important wild duck foods. Growth from rootstocks, seeds and fragmentation parts all played important roles in the perpetuation of the species discussed.

Ewart (21) points out that passage through the alimentary canals of birds greatly improves the germination of various water plant seeds.

Morinaga (55) found that alternating temperatures were effective in germinating seeds of *Typha latifolia*.

Seely (75) observed that in general root reserve curves of creeping perennial weeds are of three types. Type 1 occurred where there was a relatively long period between first emergence and blooming, such as in Canada thistle and Russian knapweed. In this case the readily available carbohydrates decreased until emergence was practically completed, and then increased until just before blooming. Type 2 curves occurred where there was a relatively short period between first emergence and blooming, such as in bindweed and white top (spring emergence). In this case "complete" emergence and the bud stage approximately coincided and there was a marked reduction in reserves at this point followed by a rapid rise until the plants were mature. Type 3 curves occurred where the period between first emergence and blooming was very short or where "complete" emergence was unduly delayed. In this case reserves dropped rapidly until the bud stage. After the bud stage they usually increased slightly for a short period and then continued down until "complete" emergence took place.

Gortner (28) believed that lake vegetation might be utilized as a source of forage and thus constitute a new natural resource which could contribute to the future agricultural wealth of the region. He observed that with the exception of *Chara* sp. the lake vegetation was characterized by (a) a high ash content, (b) a high protein content, and (c) a very low "crude-fiber" content, and that the legume hays are the only commonly used forages which even approximate the lake weeds in these constituents. The following are percentage contents of the plant constituents, dry basis analysis, as found by Gortner:

Species	Dry matter	Ash	Crude protein	Nitrogen	Ether extract	Crude fiber	Nitrogen-free extract
Potamogeton pectinatus (Sago pondweed)	15.0	13.03	19.03	3.34	1.36	19.36	47.22
Medicago sativa (Alfalfa hay)	--	9.4	16.3	2.86	--	31.0	43.3

Gortner pointed out that *Elodea canadensis* has been reported by both German and Holland workers to be an excellent food for cattle and swine, being fed either green or as ensilage.

Mrsic (56) reported that in Yugoslavia it is a general custom among the peasants to use water plants as forage in districts subject to drought in summer and where there is an abundance of vegetation in the waters. In some districts the peasants may be seen using the river vegetation as fodder throughout the whole year. The water plants are cut just above the roots and dragged out with rakes. The plants are dried only for a short time--long enough to drain off the water, and are then used as fodder while still fresh. The cattle like this fodder and digest it as easily as the ordinary green fodder. Mrsic concluded that where there is an abundance of water plants in clear cool waters the former can be used for fodder to great advantage.

Harper and Daniel (32) found the following percentage chemical composition for some common western aquatic species:

Species	Nitrogen	Phosphorus	Calcium
Elodea canadensis	2.032	0.192	9.296
Potamogeton nodosus	1.734	.200	1.921
Potamogeton foliosus	1.998	.280	2.393
Potamogeton pectinatus	1.977	.157	2.996
Typha latifolia	2.046	.183	0.462
Spirogyra sp.	1.012	.101	6.787

Metcalf (50) lists Chara spp., Potamogeton pectinatus and Potamogeton foliosus as some of the most important duck foods in North Dakota lakes.

Bennett (6) found that reduced yields of bluegills seemed to be corrected with the spread of Potamogeton foliosus.

OBJECTIVES

In order that the field of waterweed control might be more thoroughly understood and its various aspects properly evaluated, it was believed desirable to conduct investigations along diverse phases of the problem so that possible control measures, evolved from the study, might be considered in proper perspective. The studies here reported included plant migration, biological control, water depth control, chemical control, and mechanical control of submersed and emergent waterweeds, and also included studies on the woody phreatophyte, salt cedar. Restoration of the originally designed carrying capacity of irrigation water distribution systems so far as possible by plant growth control or eradication was the main purpose of these investigations.

Much of the information contained herein should be of value, too, in recreational areas where water plants often are a nuisance.

Because of recent widespread success of certain phenoxy-acetic acid derivatives on land weeds, the effect of these compounds on obnoxious submersed and emergent aquatic weeds was included in the studies reported here. Weed control investigations, using contact and systemic herbicides as well as biological competitors, were made on some of the important aquatic vascular plants which impede flow of western irrigation waters.

Plant regenerative power appears to be at its lowest ebb when food reserves are low. Accordingly, application of each herbicide, contact or systemic, was made at that time to attain the most successful eradication or control.

Since carbohydrates in the crown, rhizome, and root of cattail plants appear to be equally available to the plant for new growth, the word "root" is used in this study to include that part of the underground tissue below the line of fibrous root emergence.

It was recognized that an effective application of phytocides appears to require not only that fatty oxidized excretions forming the cuticle be penetrated by organic solvents, but that these solvents be used in proper dilution as well (7). Therefore, studies were made of the relative facilities with which weedicides are absorbed and with which they, or their effects, are moved within the various plant parts under varied external conditions. Studies of effects of herbicides on certain plant physiological processes were also included to provide a better understanding of any particular weed killer performance.

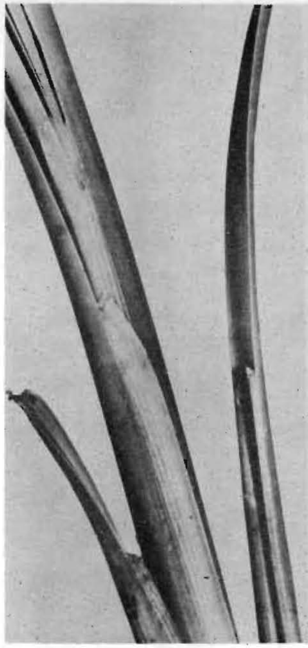
IDENTIFICATION OF PLANTS AND CHEMICALS USED IN STUDY

PLANTS

As will be shown under discussion of results, differences in effects of herbicides on water plants can be accounted for, in part at least, by variation in genera, species, or varieties of species present at the time of treatment. Therefore, it is of considerable importance that proper plant identification be made if kind and amount of herbicide applied are to be appropriate for any given weed problem. Identifying aspects of two relatively important waterweeds, broad- and narrow-leaved cattails, which differ considerably in their susceptibility to 2,4-D herbicidal applications, are illustrated in Figure 2.

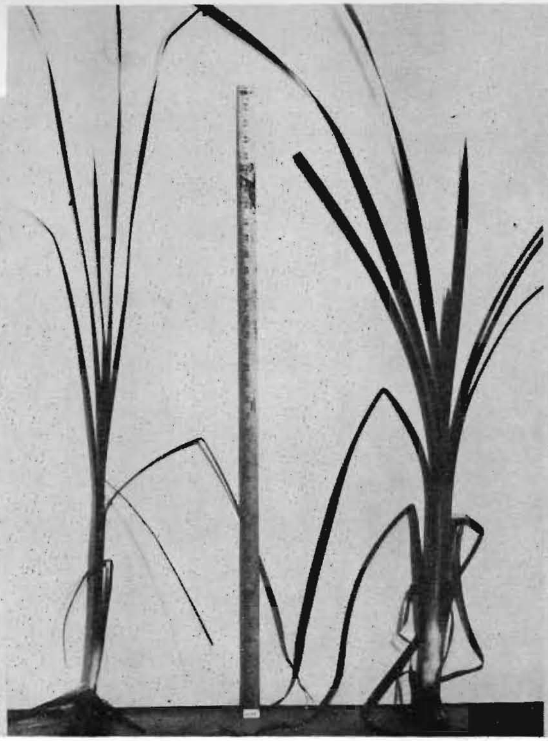
Other common troublesome submersed aquatic plants are illustrated in Figures 3 and 4.

Weed control and fertilizer investigations were performed on the following species and varieties of plants, which include many of the



Narrow-leaved cattail
Typha angustifolia L.

Leaf auricle present



Narrow-leaved cattail
Typha angustifolia L.

Broad-leaved cattail
Typha latifolia L.

Cattail vegetative appearances

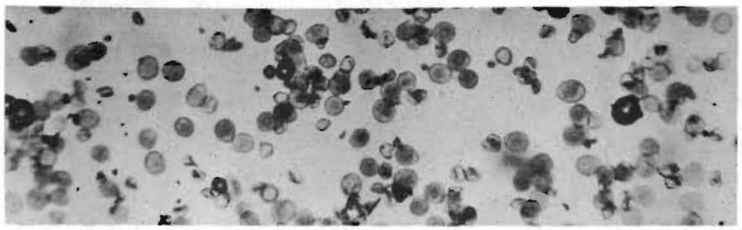
Narrow-leaved cattail
Typha angustifolia L.

Broad-leaved cattail
Typha latifolia L.

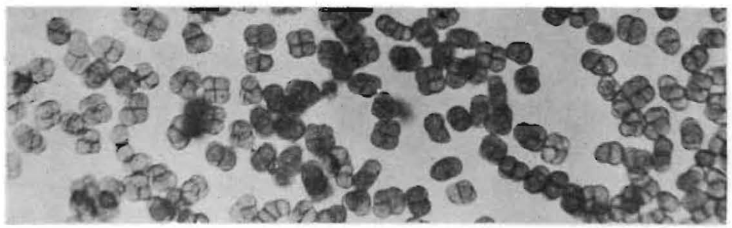
Cattail fruiting bodies

Broad-leaved cattail
Typha latifolia L.

Leaf auricle absent

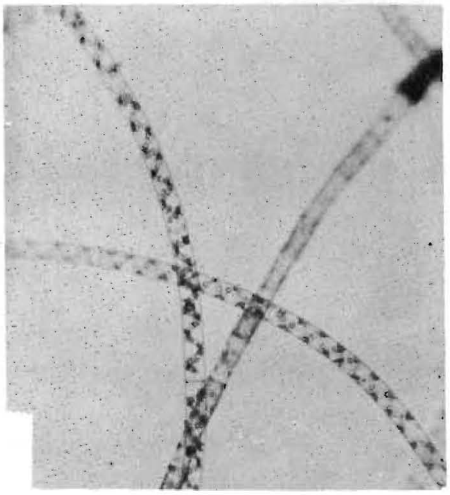


Narrow-leaved cattail pollen grains. Magnification 140 X
Typha angustifolia L.

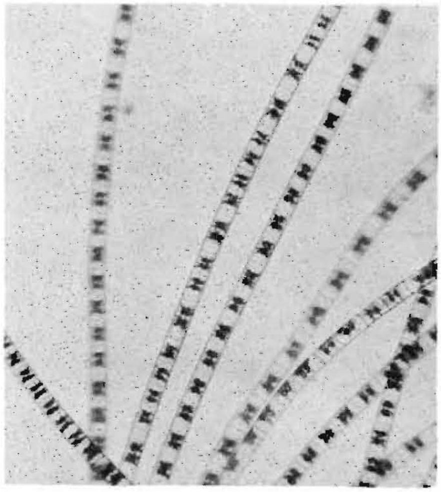


Broad-leaved cattail pollen grains. Magnification 140 X
Typha latifolia L.

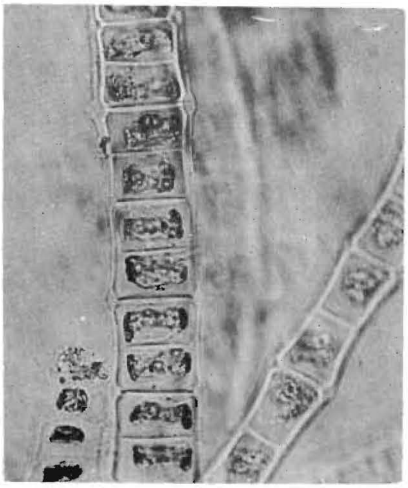
Fig. 2 Field aspects of broad- and narrow-leaved cattail plants



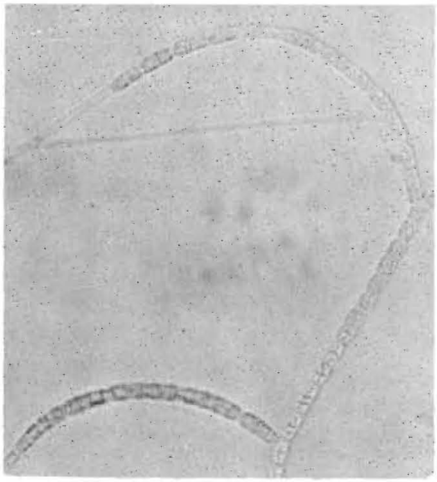
Spirogyra sp. (x 125)



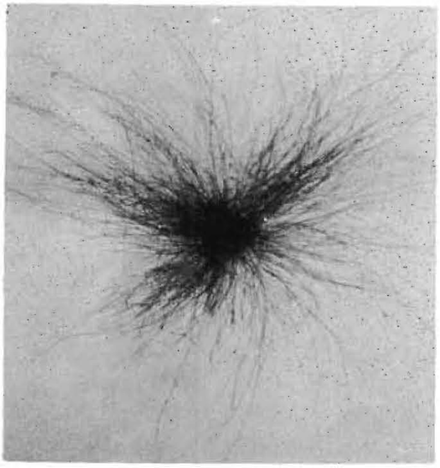
Zygnema sp. (x 110)



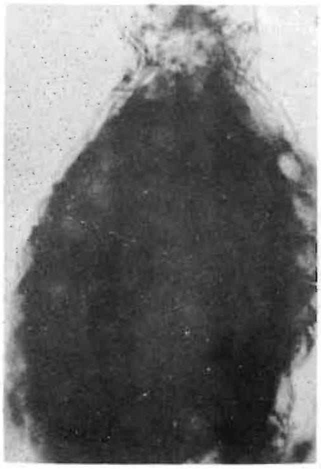
Ulothrix sp. (x 500)



Bulbochaete sp. (x 125)

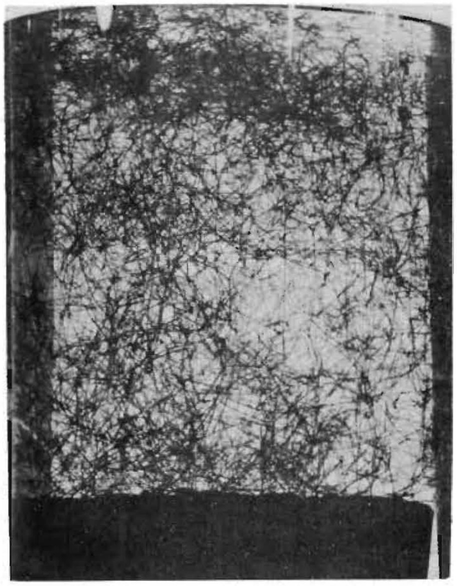


Cladophora sp. (x 2)

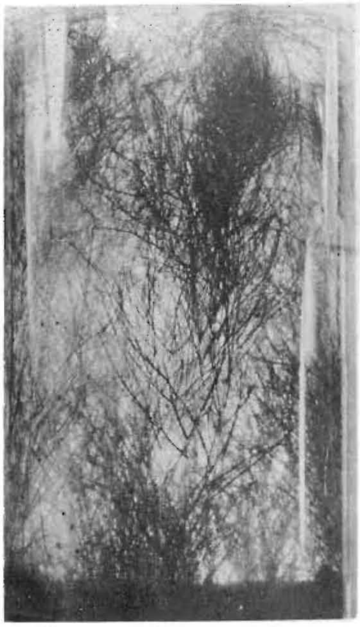


Oogonium of Chara sp. (x 140)
Capped by 5 cells

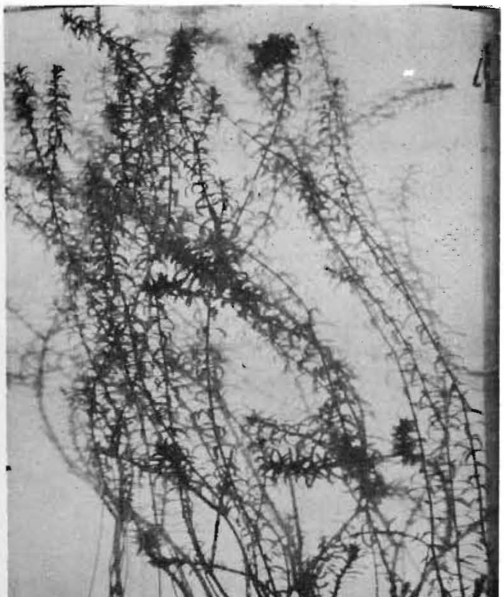
Fig. 3. These algae are some of the more common ones often found to replace vascular plants after the latter are killed with systemic herbicides.



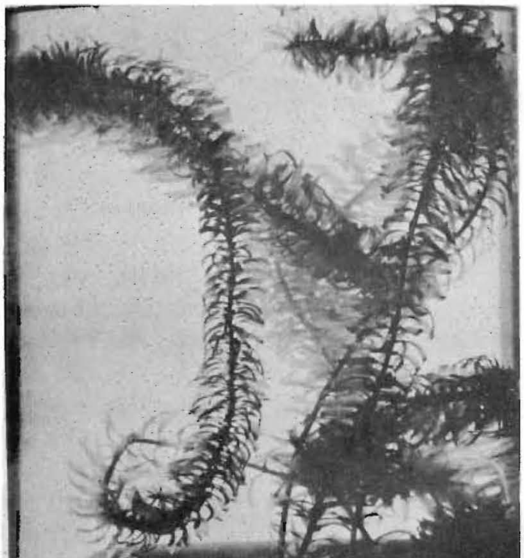
Horned pondweed (x 1/2)



Sago pondweed
(horsetail moss) (x 1/2)



Western waterweed
(Nuttall's waterweed) (x 1/2)



Dense waterweed (x 1/2)

Fig. 4 Some of the troublesome waterweeds used in laboratory and greenhouse studies.

most troublesome waterweeds that impede irrigation water flow in the United States west of the 100th meridian:

Species	Common Name
A. Pond scums (algae)	
Bulbochaete sp. Agardh.	Pond scum
Cladophora sp. Kutzing	Pond scum
Oedogonium sp. Link	Pond scum
Spirogyra sp. Link	Pond scum
Ulothrix sp. Kutzing	Pond scum
Zygnema sp. Agardh.	Pond scum
B. Pondweeds	
Potamogeton foliosus Raf. var. niagarensis (Tuckerm.) Morong	Leafy pondweed
P. nodosus Poiret	American pondweed
P. pectinatus L. var. interruptus Kitaibel	Gigantic sago pondweed (Horsetail moss)
P. pectinatus L.	Slender sago pondweed
P. richardsonii (Ar. Benn.) Rydb.	Richardson's pondweed
Zannichellia palustris L.	Horned pondweed
C. Other submersed rooted aquatics	
Chara sp. Valliant	Stonewort
Eleocharis acicularis (L.) R. and S.	Needle spike rush
Elodea densa (Planch.) Caspary	Dense waterweed
E. nuttallii (Planch.) St. John	Western waterweed
Heteranthera dubia (Jacq.) Mac M.	Water star grass
Nasturtium officinale R. Br.	True water cress
Sagittaria subulata (L.) Buchenau	Dwarf arrowhead
D. Emergent aquatics	
Carex aquatilis Wahl.	Water sedge (Ripgut grass)
C. atherodes Spreng.	Awned sedge (Oregon sugar grass)
Eichornia crassipes (Mart.) Solms.	Water hyacinth
Eleocharis palustris (L.) R. and S.	Marsh spike rush
Myriophyllum brasiliense Camb.	Parrot's feather

Species	Common Name
Typha angustifolia L.	Narrow-leaved cattail
Typha latifolia L.	Broad-leaved cattail

E. Woody species

Populus deltoides Marsh.	Cottonwood
Prosopis glandulosa Torr.	Mesquite
Tamarix gallica L.	Salt cedar

F. Crop

Lycopersicum esculentum Mill.	Chalk's Early Jewell tomato

It has been observed in the laboratory that the coarse form of sago pondweed (gigantic sago), so common in flowing waters of the West, is much more resistant to chemicals than is the slender form, which is more common in the relatively quiet waters of the West. Thus, it seems desirable in this study to make a distinction between the two forms of *Potamogeton pectinatus* L. It should be pointed out here that while horned pondweed, *Zannichellia*, belongs to the pondweed family, Zosteraceae, it is not a true pondweed. This common name refers solely to species of *Potamogeton*. All plant identifications except that of awned sedge were made by the senior author in the laboratory at Federal Center, Denver, Colorado.

CHEMICALS

Studies discussed later will show that the results of herbicidal application are dependent upon a number of factors, including kind of chemical and type of formulation.

The following chemicals were employed in these studies:

Common Name of Herbicide or Class of Compounds	Chemical Name and/or Composition
2,4-D	2,4-dichlorophenoxyacetic acid: free acid, amine salt, sodium salt, butyl, isopropyl, and tetrahydrofurfuryl esters
2,4,5-T	2,4,5-trichlorophenoxyacetic acid: butyl, isopropyl, and tetrahydrofurfuryl esters
Commercial borate-I	Sodium borate (anhydrous)
Commercial borate-II	Sodium borate (hydrated)

Common Name of Herbicide or Class of Compounds	Chemical Name and/or Composition
Commercial borate-III	Sodium borate mixture
Chlorate	Sodium chlorate ($NaClO_3$)
	Sodium meta-arsenite ($NaAsO_2$)
Blue vitriol or blue stone	Cupric sulfate ($CuSO_4 . 5H_2O$)
Sulfate of ammonia	Ammonium sulfate ($(NH_4)_2SO_4$)
CMU	3-(p-chlorophenyl)-1,1-dimethylurea
PDU	Phenyldimethylurea
Endothal	Disodium 3,6-endoxohexahydro-phthalate
Sodium TCA	Sodium trichloroacetate
RADA	Rosin Amine D acetate
MH	Maleic hydrazide
PCP	Pentachlorophenol
Sodium PCP	Sodium pentachlorophenate
Aliphatic solvent	Kerosene
Aromatic solvents	Benzene Monomethylbenzene (toluene) Dimethylbenzene (xylene) Trimethylbenzene
Chlorinated benzenes	Monochlorobenzene Dichlorobenzene Trichlorobenzene Polychlorobenzene
BHC	Alpha-benzene hexachloride
Commercial Aquatic Weed Killer-I	Methylated benzenes
Commercial Aquatic Weed Killer-II	Methylated benzenes

Common Name of Herbicide or Class of Compounds	Chemical Name and/or Composition
Nigrosine dye	
TEA	Triethanolamine
TBP	Tributylphosphate

Wetting, sticking, and emulsifying agents--Manufacturers

(a) Span 20 and Tween 20, 40, and 85 (Atlas Powder Company)

(b) Vatsol OT-B (American Cyanamid Company)

(c) WA (O. E. Linck Company, Incorporated)

(d) R-615 (Griffin Chemical Company)

(e) VL-600 (B. F. Goodrich Chemical Company)

ANATOMY OF AQUATIC PLANTS DISCUSSED IN THIS STUDY

Transverse sections prepared in accordance with methods suggested by Sass (71) and Corrington (11) of leaves or portions of leaves are illustrated in Figure 5. Transverse sections of stems or rhizomes of most of the aquatic plants discussed in this study are illustrated in Figures 6 and 7. Variation in the development of the protecting and conducting features of the various aquatic plants studied could easily account for known reaction differences of various plants toward any given herbicide or herbicidal formulation.

While in this study the optimum amount of herbicidal 2,4-D per acre per growing season for controlling vascular plants varied between 3 and 35 pounds, it was believed that further study of cuticle penetrants would permit highly satisfactory field results with the lower rates of 2,4-D applied. Aquatic plants, for the most part, (Figures 3 to 5) have a relatively well-developed phloem system. There is every reason to believe, therefore, that once the 2,4-D reaches the phloem elements it, or its effects, will move throughout the plant system. Stonewort and pond scum (see Figures 4J and B, respectively) have poorly developed food conducting elements and, therefore, probably are not affected by 2,4-D. However, it has been shown that the pond scums actually assimilate 2,4-D (63).

Structural changes in vascular hydrophytes considered as adaptations to aquatic environments are reductions of protecting, supporting, and conducting tissues and frequent provision for aeration and buoyancy the full length of the plant, especially in the mesophyll of leaf, ground tissue of petiole, and cortex of stem and root, by the development

A. Sago pondweed (Potamogeton pectinatus) leaves. X 40

B. American pondweed (Potamogeton nodosus) portion of floating leaf. X 330

C. American pondweed (Potamogeton nodosus) portion of submersed leaf. X 330

D. American pondweed (Potamogeton nodosus) portion of floating leaf. X 15

E. American pondweed (Potamogeton nodosus) submersed leaves. X 15

F. Leafy pondweed (Potamogeton foliosus) leaf. X 40

G. Cottonwood (Populus deltoides) portion of leaf. X 8

H. Horned pondweed (Zannichellia palustris) leaf. X 150

I. Broad-leaved cattail (Typha latifolia) leaf. X 7

J. Narrow-leaved cattail (Typha angustifolia) leaf. X 8

K. Richardson's pondweed (Potamogeton richardsonii) portion of leaf. X 27

L. True water cress (Nasturtium officinale) portion of leaf. X 32

M. Parrot's feather (Myriophyllum brasiliense) leaf. X 165

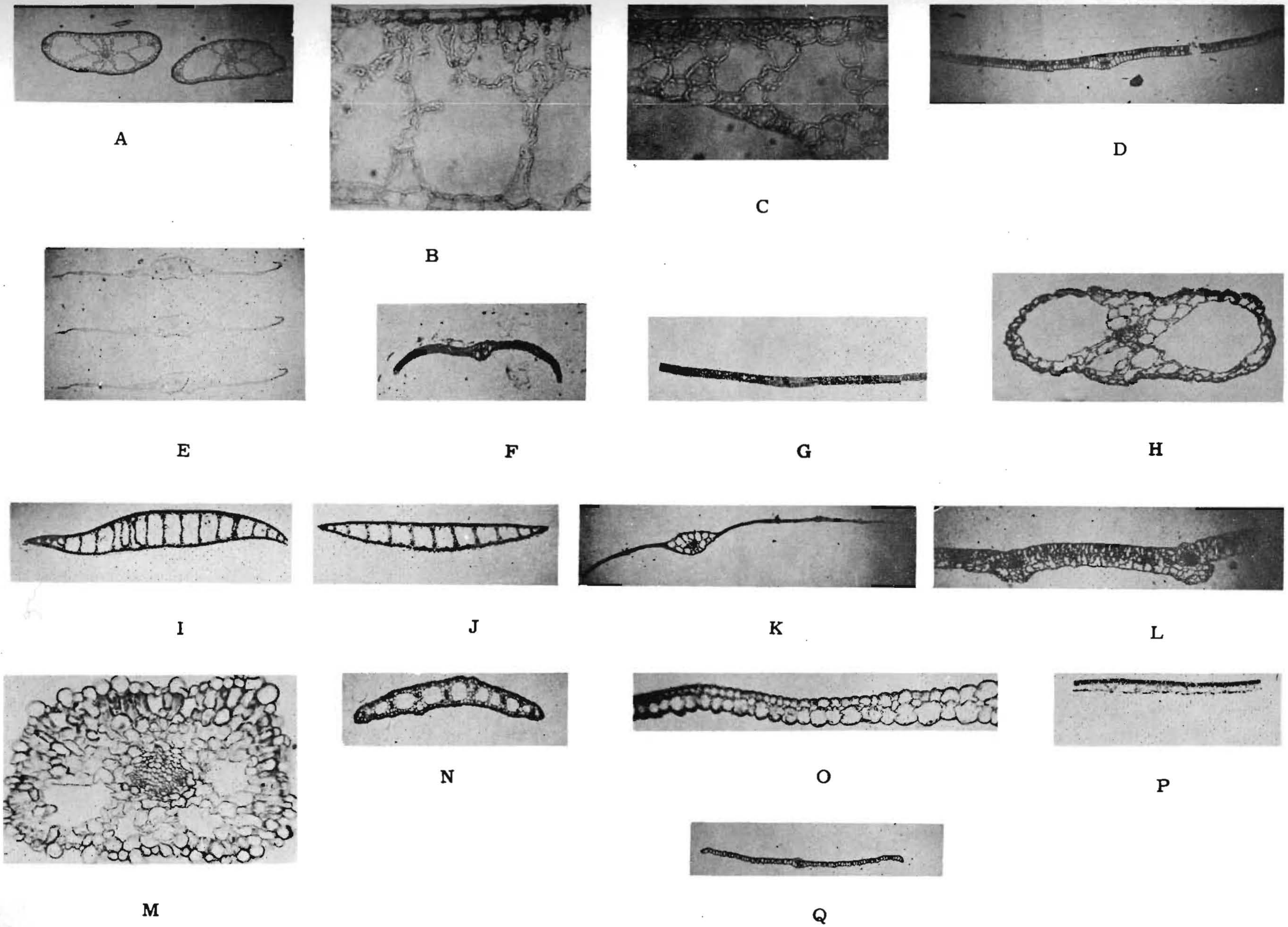
N. Water star grass (Heteranthera dubia) leaf. X 35

O. Western waterweed (Elodea nuttallii) portion of leaf. X 165

P. Water hyacinth (Eichornia crassipes) portion of leaf. X 8

Q. Dense waterweed (Elodea densa) leaf. X 28

Figure 5--Leaf transverse sections of representative plants growing in and along irrigation canals of the western United States.


A
B
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Q

A. True water cress (Nasturtium officinale) stem. X 32

B. Pond scum (Spirogyra sp.) filament. X 150

C. Parrot's feather (Myriophyllum brasiliense) stem. X 165

D. Water star grass (Heteranthera dubia) stem. X 40

E. Marsh spike rush (Eleocharis palustris) stem. X 35

F. Needle spike rush (Eleocharis acicularis) stem. X 150

G. Western waterweed (Elodea nuttallii) stem. X 28

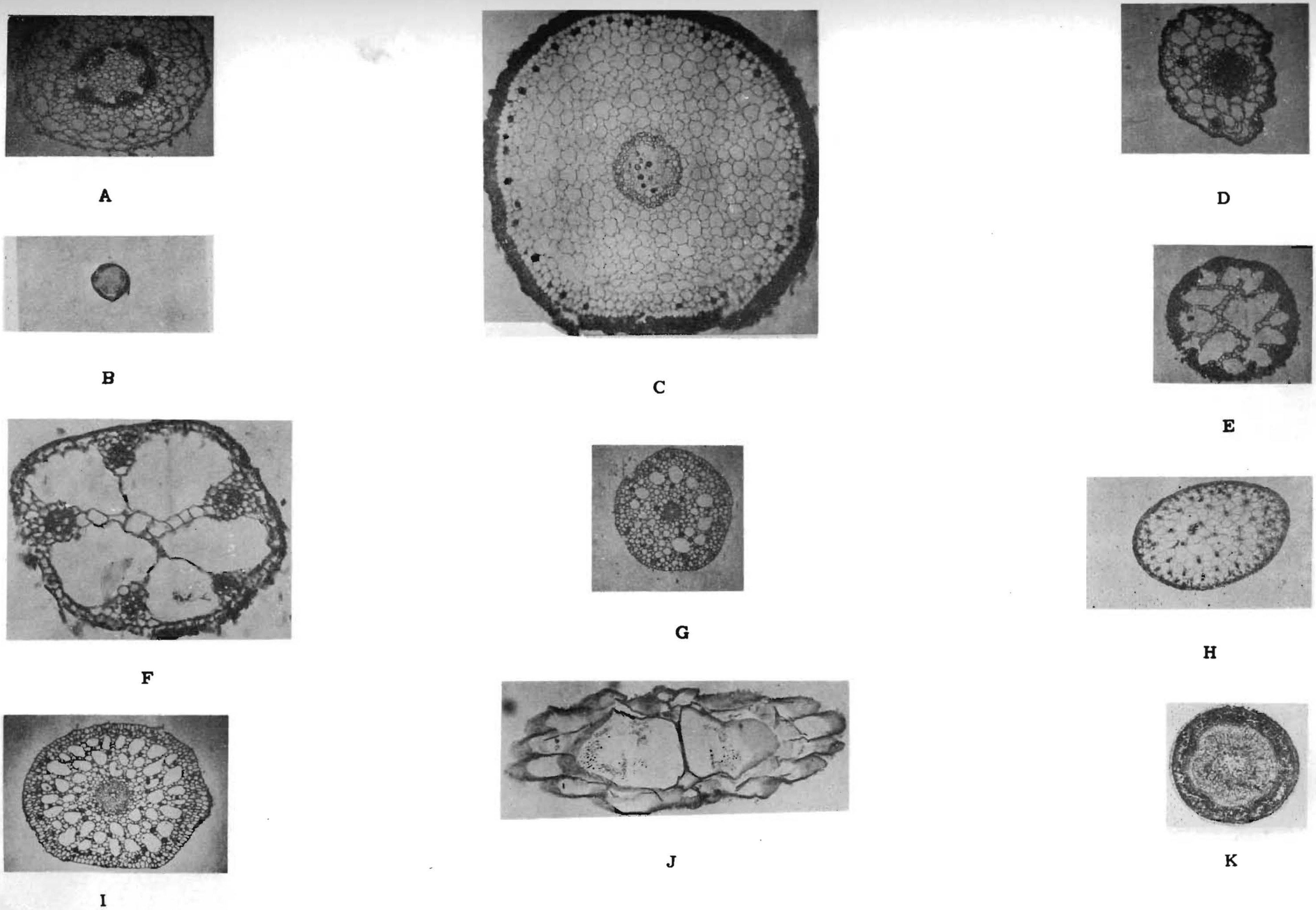
H. Water hyacinth (Eichornia crassipes) petiole. X 14

I. Dense waterweed (Elodea densa) stem. X 27

J. Stonewort (Chara sp.) stem. X 150

K. Cottonwood (Populus deltoides) stem. X 14

Figure 6--Stem, rhizome, and petiole transverse sections of representative plants growing in and along irrigation canals of the western United States.


A
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C
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A. Sago pondweed (*Potamogeton pectinatus*) stem. X 165

B. American pondweed (*Potamogeton nodosus*) rhizome. X 40

C. Leafy pondweed (*Potamogeton foliosus*) stem. X 150

D. Water sedge (*Carex aquatilis*) rhizome tissue. X 500

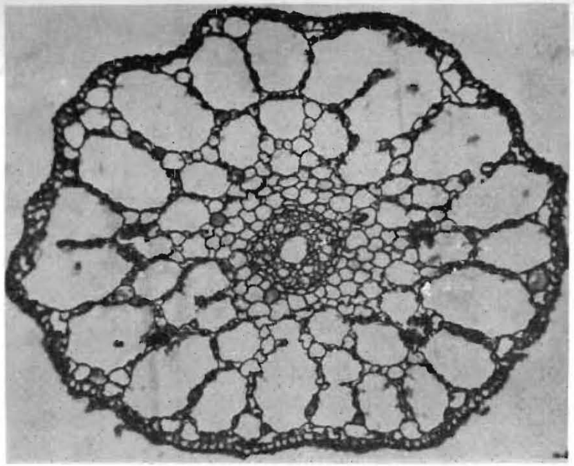
E. Horned pondweed (*Zannichellia palustris*) stem. X 165

F. Narrow-leaved cattail (*Typha angustifolia*) rhizome. X 8

G. Broad-leaved cattail (*Typha latifolia*) rhizome. X 8

H. Richardson's pondweed (*Potamogeton richardsonii*) rhizome. X 40

Figure 7--Stem, rhizome, and petiole transverse sections of representative plants growing in and along irrigation canals of the western United States.



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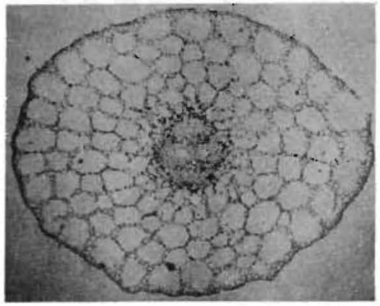

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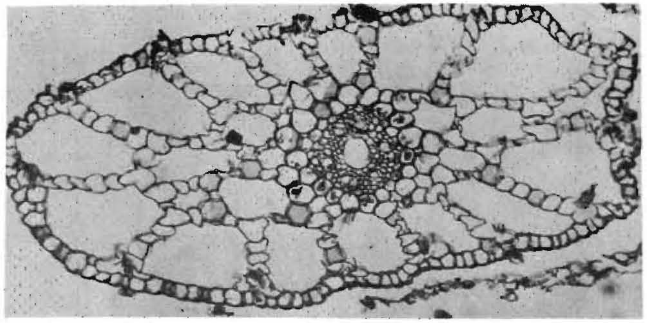

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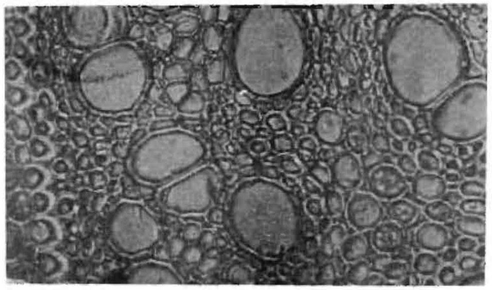

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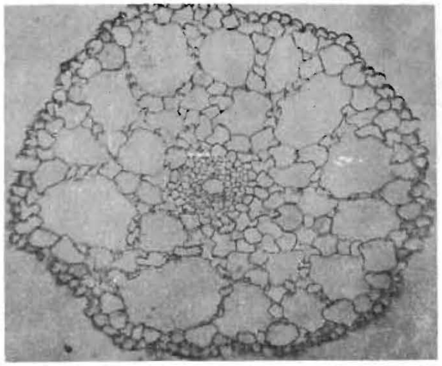

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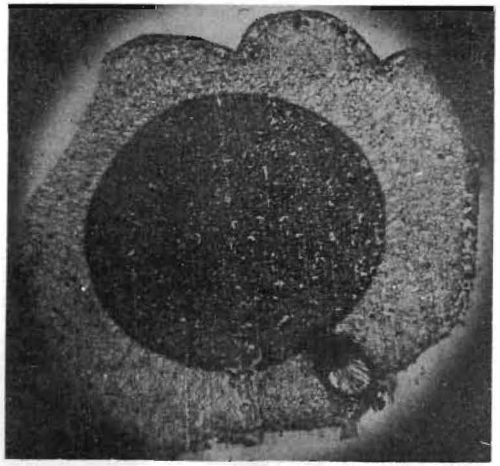
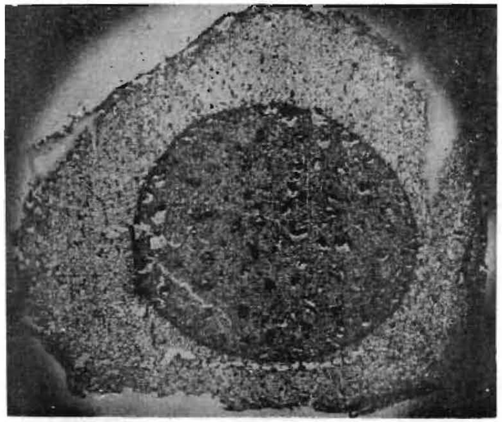
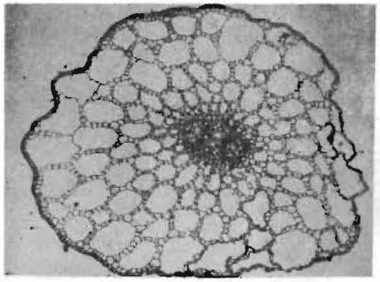


F



G



H

of air chambers (2, 18). Roots and rhizomes buried in the asphyxiating mud may thus be aerated more readily. Finely divided, long, thin, radial, cylindrical, terete leaves with absence of dorsiventrality allow for increased contact between leaf surface and surrounding water. Absorption of gases and of some nutrients takes place directly from the water by stem and leaf. The epidermis has only a slight development of cuticle but commonly contains chloroplasts and may thus form a considerable part of the photosynthetic tissue, especially where the leaves are very thin. Epidermal cells have straight walls, and the majority of aquatic plants are believed to store sugar rather than starch. The reduced mesophyll, showing little differentiation into palisade and spongy parenchyma, serves mainly for storage purposes.

In submerged tissues of hydrophytes, stomata and hairs are generally wanting and transpiration is weak. The floating leaves, however, have abundant stomata upon the upper surface, e.g., in American pondweed. The greatest proportional reduction in the vascular tissue occurs in the xylem and lignification is often very poor. In may forms the xylem consists of only a few elements, even in the stele and main vascular bundles. Less commonly, xylem elements are entirely lacking. In these cases usually there is a more or less well-defined xylem lacuna to mark the normal position of the xylem.

Phloem tissues, on the other hand, are in most cases fairly well developed as compared with the xylem. They resemble the phloem tissue of reduced herbaceous plants generally in that the sieve tubes are small as compared with those of woody plants. The vascular system is often condensed into a central strand, devoid of secondary thickening, and individual bundles cannot be distinguished. The endodermis is often weakly developed or may be entirely wanting.

Aquatic plant stems consist of either an abbreviated axis bearing a tuft of long narrow leaves or thin, elongated, branched stems rising wholly or partially into the water, clothed with leaves and often capable of rooting at the nodes. Owing to the bouyancy of the stems due to the air in the intercellular spaces, each axis is to a large extent relieved of the task of supporting the weight of its branches. Plants frequently grow actively in front by means of rhizomes while they die away behind and may thus be regarded as being in a state of perpetual youth.

Aquatic plant roots are sometimes extremely reduced or even entirely absent. Too, a considerable system of adventitious roots may be developed. The function of root anchorage has assumed a greater importance, while the function of absorption is less pre-eminent. In free-floating plants roots preserve equilibrium and when green in color assist in food assimilation. The roots which are flexible occasionally do not have root hairs.

It is important to note here the finding of Mitchell and Brown (53) that the stimulus resulting from 2,4-D application on bean plants was closely associated with translocation of organic food materials, and that this stimulus occurred as a continual flow under conditions favorable for carbohydrate translocation and probably was confined to the living phloem or parenchyma cells.

Thimann (83) and Weaver and DeRose (89) have shown that stomata are not important portals of entry for phenoxyacetic acid derivatives and that, when applied to the aerial portions of plants, the compound moves downward whenever translocation of synthesized materials occurs.

This downward movement of the phenoxyacetic acid stimulus through the living phloem or parenchyma cells is very important for, as pointed out, the phloem tissues of aquatic plants are in most cases well developed as compared with the xylem.

SUBMERSED WATERWEEDS

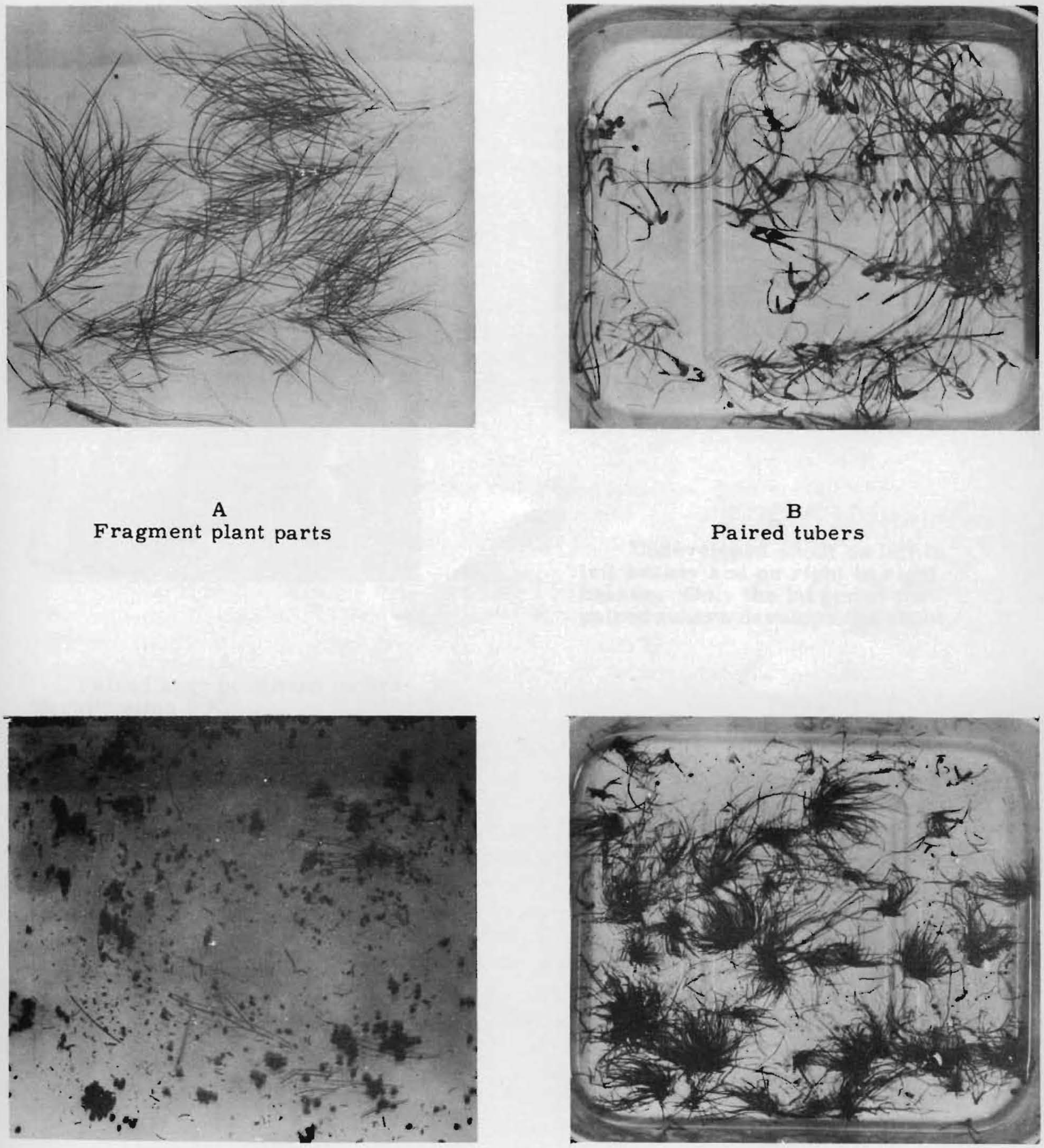
Because the studies reported here cover so many different phases and the techniques varied so widely, procedure and results are discussed together for each phase.

METHODS OF PROPAGATION

In addition to vegetative propagation from rhizomes during the normal growing season, four distinctly different methods by which field propagation of sago pondweed may be brought about are illustrated in Figures 8 and 9. These methods include growth from: (a) fragmented plant parts, (b) paired tubers, (c) fruits or "seeds," and (d) vegetative tussocks.

It was observed by Moore (54) and in the Denver laboratory that when tubers occur in pairs, as is the case of sago pondweed, only the larger one developed the shoot. The smaller tuber did not sprout unless it became detached. In that case only, it developed an individual plant. This is illustrated in Figure 9. American pondweed accomplishes vegetative propagation also by subterranean scaly buds which generally grow two or more at the end of the rootstock. In an experiment carried on in the Denver laboratory all buds developed growth at the same time in some cases. In other cases, only the larger one developed the shoot.

Seed germination like growth from tubers frequently takes place over an extended period (60). Sago pondweed seeds were gathered July 12, 1949, from the Federal Center lake at Denver, Colorado, and kept in cold storage through the winter. On April 19, 1950, 100 seeds were placed inta covered 2-ounce jar containing tap water, which in turn was placed in the greenhouse to observe germination.



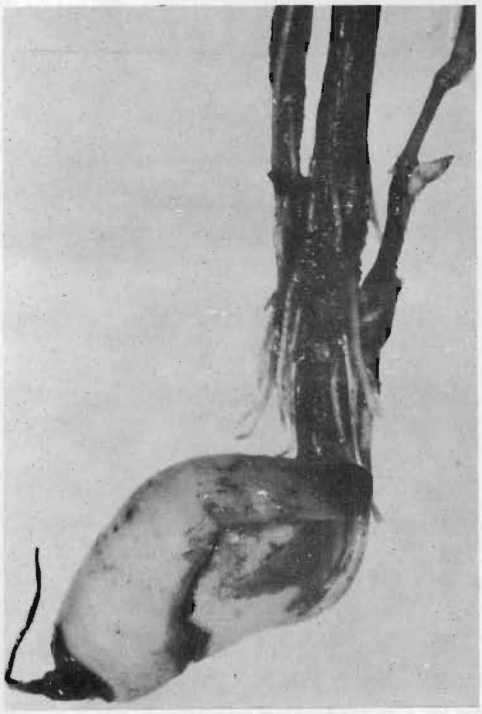
A
Fragment plant parts

B
Paired tubers

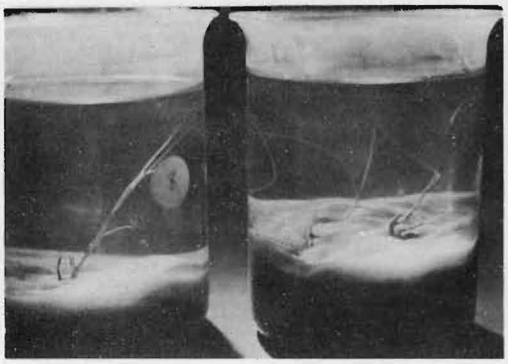
C
Fruits or "seeds"

D
Vegetative tussocks

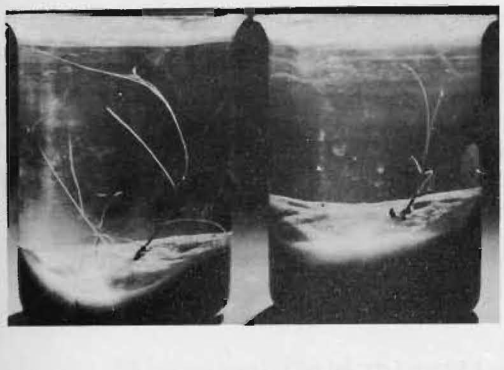
Fig. 8 Different kinds of reproductive propagules of sago pondweed.



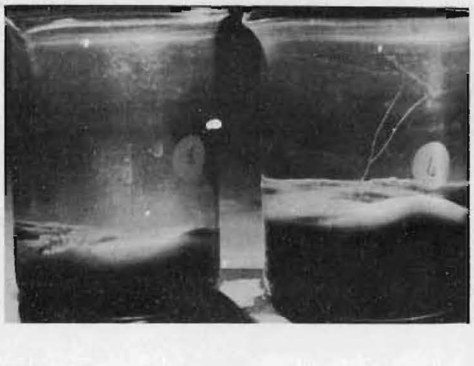
A
Paired sago pondweed tubers
Magnification 3 X.



B
Undeveloped shoot on left in left beaker and on right in right beaker. Only the larger of the paired tubers develops the shoot.



C
When shoot from the larger tuber is severed at the sand line, the smaller of the paired tubers develops the shoot.



D
Sago pondweed regrowth in right beaker after severing plant growth from smaller of paired tubers at sand line.

Fig. 9 Smaller of the paired sago pondweed tubers develops a shoot when shoot from the larger tuber is severed at the sand line.

Germination proceeded as follows:

Germination date	Number of germinated seeds removed from jar
4/24/50	18
5/1/50	2
5/5/50	3
5/9/50	2
5/12/50	2
5/15/50	2
5/22/50	1
6/2/50	0
6/16/50	0
7/10/50	3

PLANT MIGRATION

Procedure

In September 1952, a canal 125 feet long, 13 feet wide, having an average depth of 2-1/2 feet, and free of aquatic plant growth was filled with fresh water, the level and slow movement of the water being maintained by using a garden hose flowing approximately 11-1/2 gallons per minute. Three partitions of ripgut grass, each approximately 8 inches in width, were planted across the long axis of the canal, dividing it into four sections, each approximately 31 feet long. Plantings of other aquatic weeds were made as follows: one clump of needle spike rush plants at each of the two ends of the first section; one clump of dwarf arrowhead plants at each end of the second section; one clump of leafy pondweed at one end and one clump of sago pondweed at the other end of the third section; a clump of narrow-leaved cattail toward the far end at the water line on one bank and a clump of broad-leaved cattail directly across the canal and at the water line on the opposite bank of the fourth section. The clumps of spike rush, arrowhead, pondweeds, and cattails were approximately 8 inches each in diameter. Observations on plant migrations were made in September 1953, one year following the initial plantings.

Results

Measured field migration in the relatively slow-flowing irrigation ditch over a 1-year period after the initial plantings was as follows:

Needle spike rush	4 feet 8 inches radial spread
Dwarf arrowhead	2 feet 3 inches radial spread
Leafy pondweed	1 foot 1 inch radial spread
Sago pondweed	1 foot 1 inch radial spread

The proposed submersed plant competitors, needle spike rush and dwarf arrowhead, spread rapidly by means of rhizomes or runners. Needle spike rush migrated about twice as far as dwarf arrowhead in the same time. The rate of spread of broad-leaved cattail and narrow-leaved cattail and survival of ripgut grass are reported later under Emergent Aquatic Weeds.

GROWTH COMPETITION BETWEEN SPECIES OF WATER PLANTS

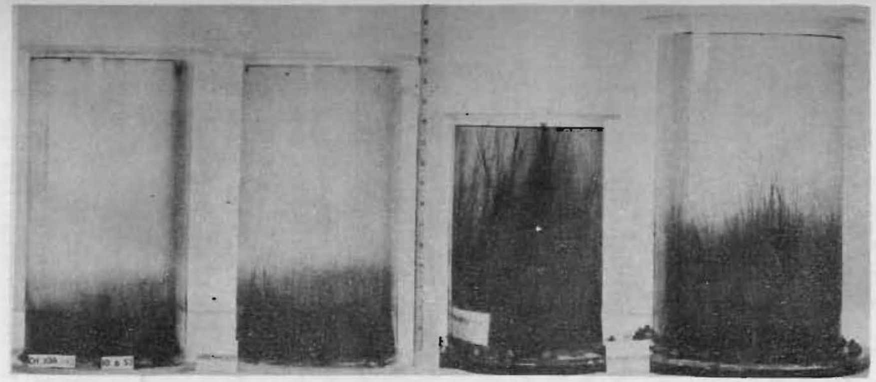
Procedure

Because of constant regrowth pressure due to the varied and effective means of field propagation of waterweeds, much of the chemical weed control on aquatic plant growth cannot be expected to have permanent suppression or elimination effects. Accordingly, it was believed desirable to find not only efficient chemicals but living competitors as well, either plant or animal, which would lessen or eliminate the more troublesome aquatic plant populations.

A study of possibly considerable economic importance was the aquatic plant competition experiments between needle spike rush and several of the more familiar plant species responsible for impeding water flow in established irrigation systems of the western part of the United States. Needle spike rush and dwarf arrowhead are aggressive, low-growing aquatic plants which spread rapidly by forming a dense growth mat along silt ditch bottoms. Greenhouse cultures of needle spike rush have been maintained for over 2 years in water depths up to approximately 2 feet. Linear measurements made on a number of specimens after this period of time (Figure 10) varied between approximately 5 and 9 centimeters and averaged 7 centimeters (2.0 - 3.5 inches, average 2.8 inches). Since the plant spreads rapidly along soil bottoms and appears to be fairly shade tolerant, it appeared desirable to investigate its ability to compete with the objectionable vascular plants which normally grow to the water's surface and thereby impede the flow of irrigation water.

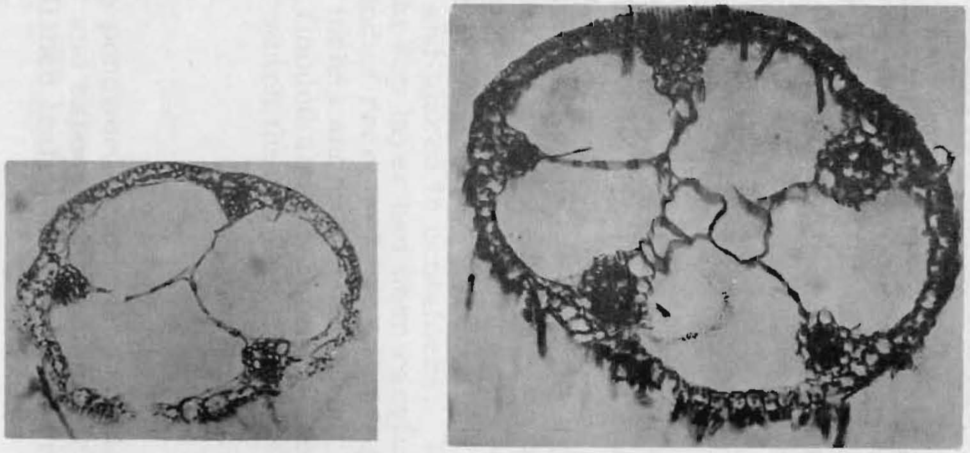
Results

Histological studies showed that needle spike rush plants grown in the absence of direct sunlight had about twice the diameter of those grown in the presence of direct sunlight. Also, it was observed that plants grown in the absence of direct sunlight grew to heights 2 to 5 times those grown in the presence of direct sunlight (see Figure 10). These responses have an important bearing on the magnitude of its resistance to irrigation water flow. While this plant has the excellent faculty of being shade tolerant under such growth conditions, its resistance to water flow under shade growth conditions is about 6 to 9 times what it is when growth develops in direct sunlight.



Needle spike rush after approximately 8 months growth when direct sunlight is

Present Absent



Transverse sections taken from needle spike rush stem growth when direct sunlight is

Present Absent

Vegetative reproduction of needle spike rush.

Fig. 10 Vegetative reproduction and effect of direct sunlight on the anatomy and physical appearance of needle spike rush growth.

It was observed that dwarf arrowhead like needle spike rush in the absence of direct sunlight grows to heights 2 to 5 times those grown in the presence of direct sunlight.

Laboratory evidence over a 2-year period indicated that either or both of these plants growing in association with the taller more obnoxious pondweed growth would, over a period of time, crowd out the pondweed growth. This suggests the desirability of planting one or both of these plants in irrigation ditches or lake bottoms for the purpose of holding shifting silt and preventing growth of the ranker growing pondweeds.

An example of plant competition found in the field was the epiphytic pond scum *Oedogonium* sp. and several species of diatoms, illustrated in Figure 11, which have so heavily coated stems and leaves of leafy pondweed growths that within 30 days after initial infestation normal photosynthetic functions of this vascular plant could not be performed, and the host plants were killed back to the water-submersed soil line, resulting in their elimination.

WATER DESICCATION BY IRRIGATION DITCH DRAINAGE

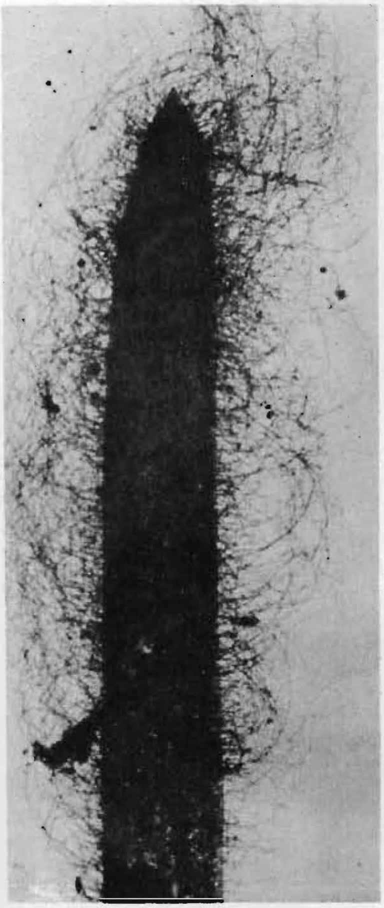
A method of waterweed control practiced in certain parts of the United States has been to drain irrigation ditches for a period of 3 days, after which water was turned back into the channels. This practice is known under certain circumstances to be effective in keeping growth down.

Procedure

In order to determine the ability of leafy pondweed to recover after complete emergence from water, some ditch bottom samples were taken from the top 1-1/2 inches of a large sand bar known to be heavily infested with leafy pondweed growth earlier in the growing season when higher ditch water covered it. During the preceding weeks, this sand bar had protruded 4 to 6 inches above the surface of flowing water in Yocum Ditch at Arvada, Colorado. The top 1-1/2 inches of the sand bar were sliced off with a shovel and placed in containers. Three types of containers were used. After the top layer had been carefully placed in the receptacles, one of each kind of receptacle was flooded with water to a depth of approximately 2 inches and one of each kind had no water added. All receptacles, both flooded and dry, were placed under a 100-watt light for 24 hours, after which the pictures illustrated in Figure 12 were taken.

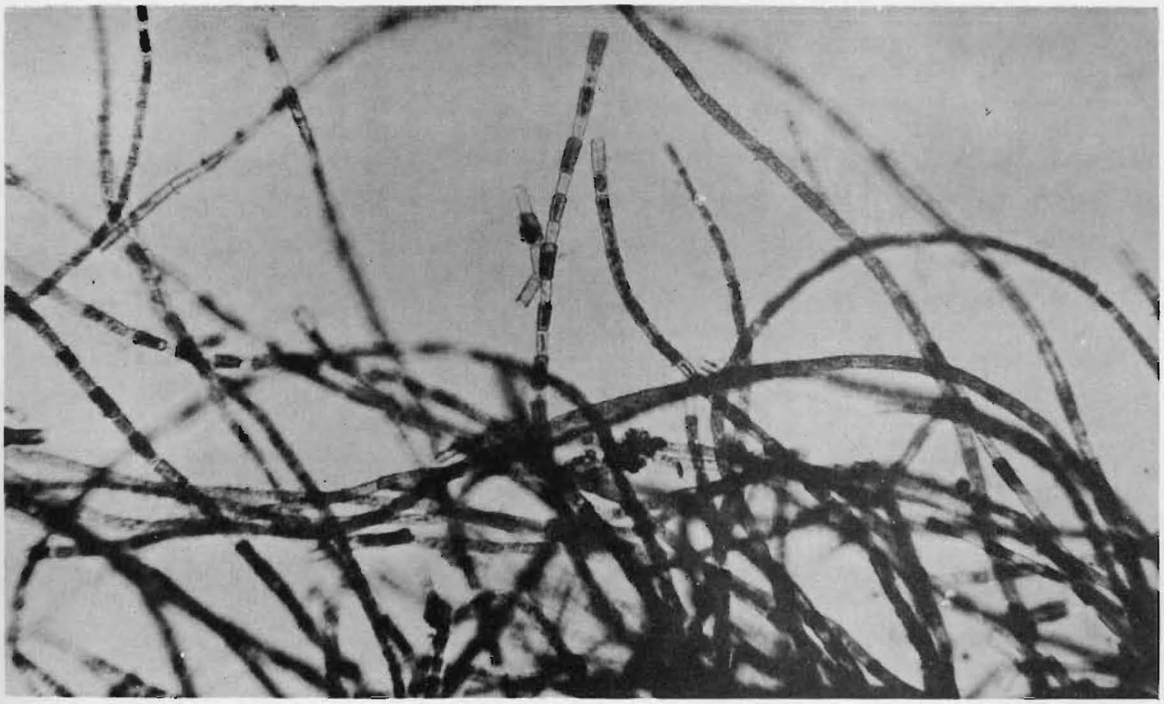
Results

In this experiment, leafy pondweed made remarkable recovery after being flooded with tap water and exposed to the light for 24 hours. This observation definitely established leafy pondweed in a group along



A

B



C

Fig. 11 Pond scum, Oedogonium sp. epiphytizing leafy pondweed.
A Leaf x 15 B Leaf tip x 80 C Oedogonium filaments x 120

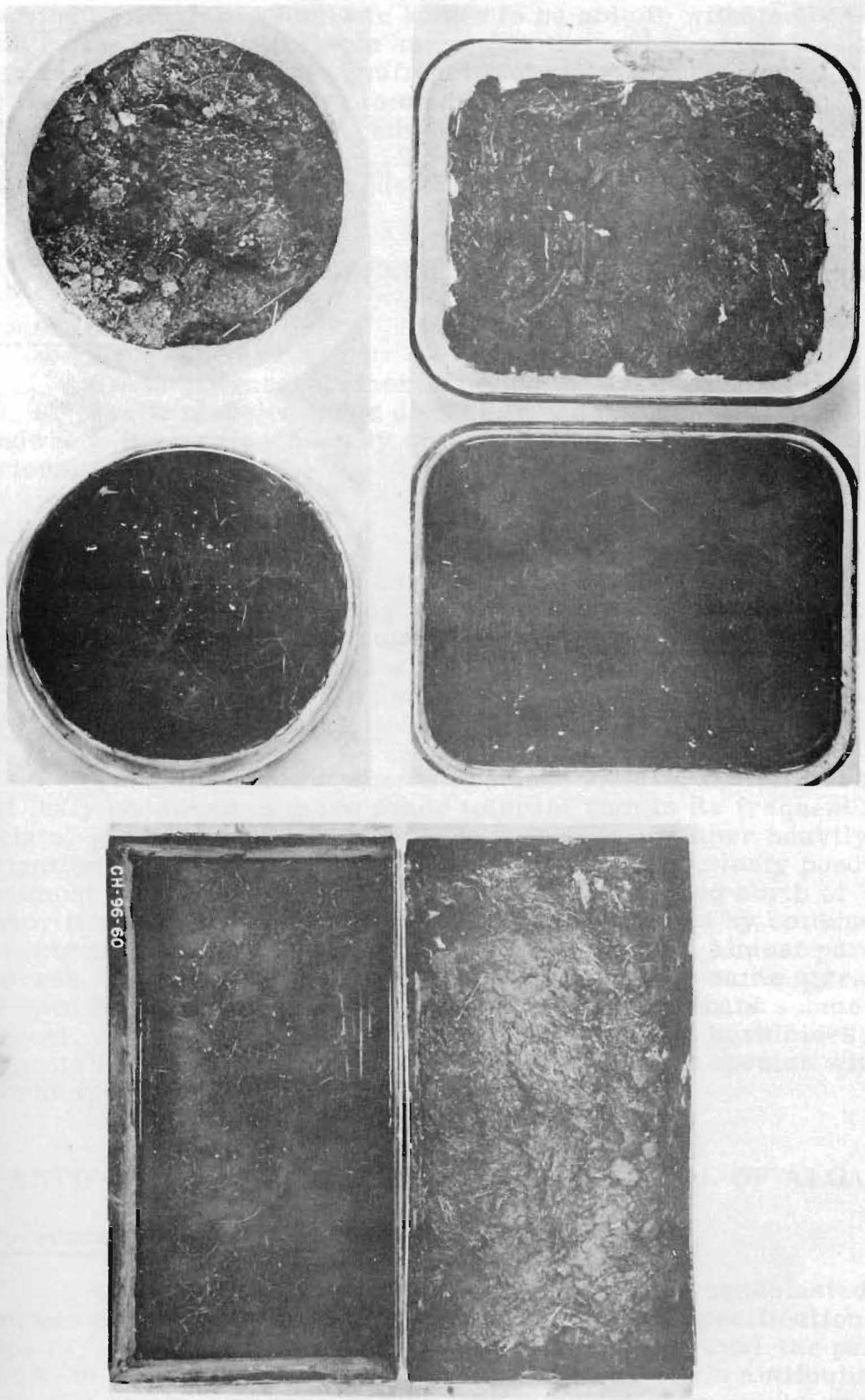


Fig. 12 Effect of flooding leafy pondweed after being subjected to 4-6 inch emergence above the surface of flowing irrigation water for an approximate 3 week period.

with American pondweed and variable-leaved pondweed (*Potamogeton gramineus*), both of which are known to be able to withstand complete emergence and remain viable as long as the soil in which they are growing remains moist. The significant fact about this finding is that draining canals for several days to control waterweeds growing in those canals will have little, if any, adverse effect on the ability of leafy pondweed to produce new growth. To eliminate leafy pondweed, it will be necessary to resort to methods other than draining a canal.

OBSERVATIONS ON EFFECTS OF TURBIDITY AND SHADING

Procedure

Turbidity measurements, using the Jackson turbidimeter (90, 91), were made on three ditches in which leafy and gigantic sago pondweeds grew in such heavy concentrations that water flow was seriously impeded.

Results

Actual turbidity readings recorded in Table 1 on three ditches in which leafy and gigantic sago pondweed plants grew showed leafy pondweed to be more shade tolerant in its growth habits. Leafy pondweed was observed growing luxuriantly in field streams even when waters were so turbid over periods of several weeks as to obstruct the view of the stream bottom.

Turbidity measurements are substantiated by field observations that leafy pondweed is more shade tolerant than is its frequent field associate, gigantic sago pondweed. In a section of rather heavily shaded irrigation ditch (Yocum Ditch) at Arvada, Colorado, leafy pondweed grows in almost a pure stand. In an irrigation ditch located north of Twin Falls, Idaho, it was noted that in the section heavily shaded by cottonwood trees growing on the bank, leafy pondweed was present in almost pure culture whereas, a few yards away in the section where the same stream traversed the open field, gigantic sago pondweed was the dominant submersed species present. Since the latter plant is more resistant to herbicides, this study suggests the possibility of replacing more resistant species with less resistant species by use of shading compounds.

ANTIFOULING PAINT COATINGS FOR CONTROL OF ALGAE

Procedure

On July 30, 1953, two metallic tanks were sandblasted and coated with two coats of red-lead primer, U. S. Federal Specification TT-P-86a, Type IV. Two other tanks coated with cold-applied coal-tar paint known as CA-50 were painted with two coats of a vinyl-resin antifouling paint applied directly over the CA-50. The third set of two tanks received two

Table 1--Readings on turbidity in three irrigation ditches supporting pondweed growth in such large quantities that water flow was seriously impeded

A. Ditch Supporting Heavy Infestation of Leafy Pondweed

Sample number	Date	Time	Surface water temperature °F	Parts per million turbidity*
1	5-16-50	11 a.m.	63.7	55.2
2	5-23-50	11 a.m.	62.6	72.7
**3	5-30-50	11 a.m.	63.5	***25.0
4	6- 6-50	11 a.m.	63.0	54.5
5	6-13-50	11 a.m.	57.5	63.0
6	6-20-50	11 a.m.	60.0	35.0
7	6-27-50	11 a.m.	61.0	46.7
8	7- 4-50	11 a.m.	63.1	26.7
9	7-11-50	11 a.m.	60.5	***25.0
10	7-18-50	11 a.m.	62.0	***25.0
**11	7-25-50	11 a.m.	64.8	***25.0

B. Ditch Supporting Medium Infestation of Sago Pondweed

Sample number	Date	Time	Surface water temperature °F	Parts per million turbidity*
1	5-18-50	10:15 a.m.		***25.0
2	7-13-50	10:45 a.m.	64.2	61.7

C. Ditch Supporting Heavy Infestation of Sago Pondweed

Sample number	Date	Time	Surface water temperature °F	Parts per million turbidity*
1	5-18-50	11:30 a.m.		***25.0
2	7-13-50	12:15 p.m.	68.0	26.7

*Turbidity as determined with Jackson turbidimeter.

**Only on the days marked with double asterisk was it possible to see ditch bottom when standing on bank of stream. Turbidity of water on other days prevented seeing ditch bottom when standing on bank.

***Turbidity was less than 25 ppm.

applications each of the asphaltic paint CA-50. Topsoil was placed in the bottom of the tanks, the tanks were filled with tap water, and planted with cultures of needle spike rush. Observations of the antifouling effect of these coatings on algae were made 10 months following planting of the tanks.

Results

Ten months after this test was under way, the antifouling paints appeared to show differences in their ability to resist fouling action of algae. Most resistant were the tanks painted with the vinyl-resin antifouling paint, followed by those painted with red-lead primer, U. S. Federal Specification TT-P-86a, Type IV. The tanks painted with cold-applied, coal-tar paint known as CA-50 appeared to be least resistant to the fouling action of the algae. It is recognized that it would have been better had the tests extended over at least a 2-year period for the interpretation of results to be completely valid. In another investigation it was found that possible surface weakening of concrete was associated with high SO_3 content of substrata suitable for algae growth (64).

EFFECT OF SILT AND CALCITE ACCUMULATION ON PONDWEED LEAF SURFACES

It has been observed that Clover Basin Lake, located about 4 miles west of Longmont, Colorado, has a relatively small amount of submersed vascular plant growth. Periodic wind storms have been observed on the lake in which the silt deposits of the shore line and lake bottom mix with the lake water, creating a temporary suspension of highly turbid water. It was believed that the silt particles, settling out of the water as it became quiet, might accumulate on the submersed aquatic plants, coating stems and leaves and thereby inhibiting or prohibiting the normal process of photosynthesis by obstructing the light source.

Procedure

A sample of the silt situated along the shore line of the lake was brought into the laboratory for study of the particle settling effect on plants growing in tanks in the greenhouse. The quantity of silt necessary to produce a uniform thickness of 0.01 inch in a tank having an exposed surface area of 759 square inches was calculated to be 7.59 cubic inches or 125 ml for each treated tank. This amount of silt, considered adequate to simulate the light-obstructing effect present in the lake, was placed in a 4-liter beaker and mixed with 3 liters of water with an electric mixer. The prepared silt suspension was uniformly mixed in the surface water of each of two tanks in which rooted leafy pondweed was growing on May 1, 1953. Two other tanks containing untreated leafy pondweed served as controls.

Results

A microscopic examination of the treated leafy pondweed cultures immediately and 2 weeks after the suspension was mixed in the surface water showed leaves coated as illustrated in Figure 13B and 13C, respectively. The former is due merely to mechanical settling of silt particles on the leaves whereas the latter is due to the chemical deposition of calcite on leaf surfaces. Both phenomena apparently seriously impede light penetration of treated leaves and the leaves and stems took on a brown appearance. New plants apparently continue to develop from attached underground shoots until food reserves are exhausted during the new plant replacement process. It appears that the formation of calcite coatings on the leaves depends on an adequate supply of calcium being available to the plant.

The most common repositories for aragonite, the less stable form of $CaCO_3$ secreted by leaf cells of the plant, are beds of gypsum (15). Present in the silt collected from the shore of Clover Basin Lake were crystals of gypsum ($CaSO_4 . 2H_2O$), showing relatively high concentrations of calcium to be present and available to the plants growing in the lake. Apparently calcite is formed by the plants in the following manner:

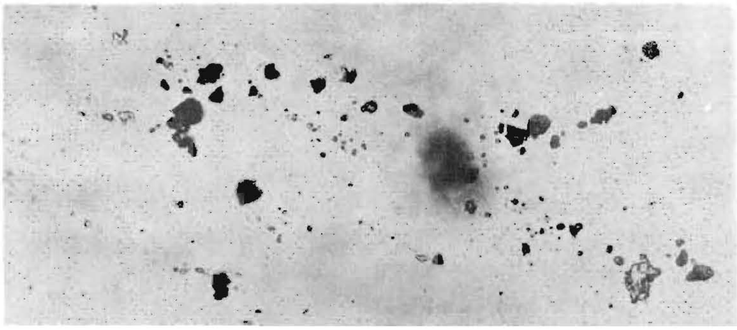
$$CaO + H_2O = Ca(OH)_2 \text{ and}$$

$$Ca(OH)_2 + CO_2 = CaCO_3 \text{ (calcite)} + H_2O$$

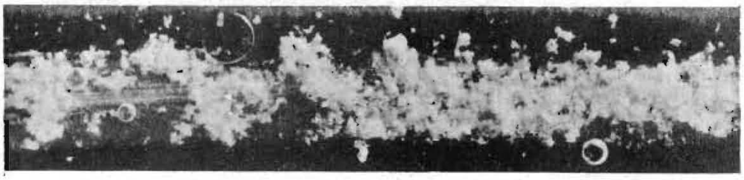
As can be seen from the photomicrographs, self-deposition of calcite on the leaves can, by obstructing light from the leaf, result in self-liquidation of the more mature plants. This phenomenon suggests the possibility of suppressing aquatic weed growth by keeping calcium available in the growing water media in order that growing vascular plants might coat themselves with the relatively light-impenetrable calcite.

USE OF CONTACT HERBICIDES IN THE CONTROL OF SUBMERSED AQUATIC WEEDS

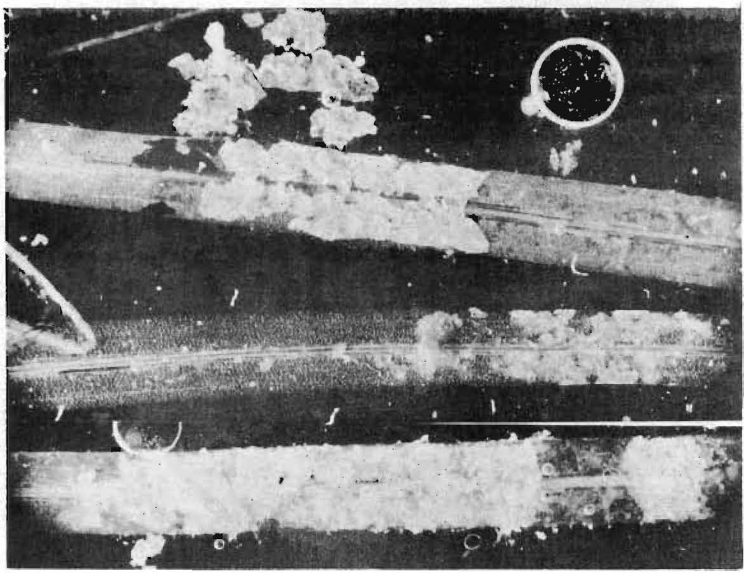
Both methylated and chlorinated aromatic solvents have been used successfully in field channels and drains obstructed by submersed weed growth. The application at rates of 6-10 gallons per cubic foot per second of flow, i.e., 450-750 ppm, over a 30-minute period frequently brings about a lowering of the water level and an increase in carrying capacity of the treated waterway (76). Increase in capacity appears to be brought about by the penetration of the administered solvent into the air tubes in stem and leaves with resulting collapse in the supporting buoyant air tube structure usually present in water plants. Figure 14 shows that 3 weeks after a patch of leafy pondweed growing in an irrigation ditch was treated with aromatic solvent, demarcation between treated and untreated areas could still be seen.



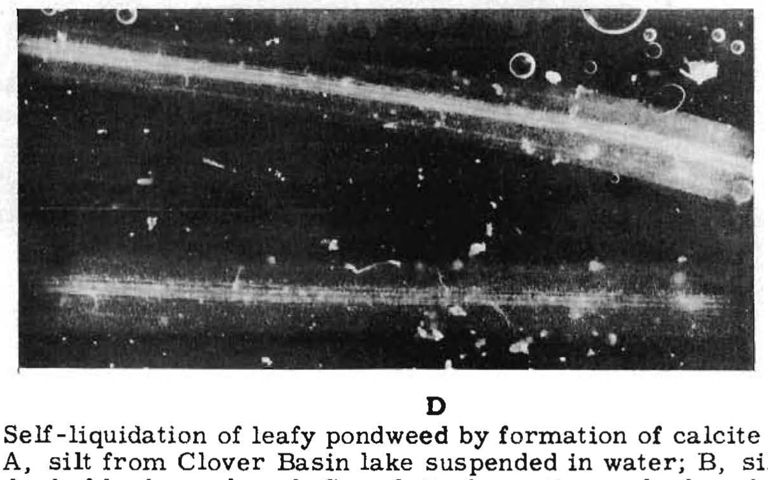
A



B



C



D

Fig. 13 Self-liquidation of leafy pondweed by formation of calcite on leaf surface. A, silt from Clover Basin lake suspended in water; B, silt particles settled on leaf of leafy pondweed; C, calcite formation on leaf surface of the plant; D, portions of two normal leafy pondweed leaves with no silt or calcite deposition.

Fig. 14 Three weeks after left half of a patch of leafy pondweed growing in an irrigation ditch was treated with aromatic solvent. Demarcation between treated and untreated area can be seen.

Beaker Test

Procedure

When performing the "Beaker Test" to determine effectiveness of chemicals as waterweed herbicides, it is important to know the amount of plant material initially treated in evaluating the amount of regrowth after treatment. In general, it would be expected that twice the amount of regrowth should result from treating twice the quantity of plant material with the same concentration of chemical. A rapid and fairly accurate method of determining quantity of plant material to be treated consisted of placing the plant material in a 150 ml pharmaceutical graduate, filling the graduate to volume with tap water, then determining the amount of water in the 150 ml pharmaceutical graduate by measuring the water in a 100 ml graduated cylinder. The differences between 150 ml and the volume measured in the graduated cylinder represented volumetrically the quantity of plant material to be treated.

Leafy pondweed and the pond scums Cladophora and Spirogyra are readily available from the field in this area and were used for the beaker test.

Eleven different aliphatic and aromatic solvent chemicals were tested at concentrations of 5, 50, 100, 200, 400, and 800 ppm. Copper sulfate and sodium arsenite were tested at concentrations of 0.5, 5, 10, 20, 40, and 80 ppm.

Two percent by volume of a nonionic emulsifier was used with all aromatic and aliphatic solvents except that the two commercial aquatic weed killers were used with the emulsifiers contained in them. No emulsifier was used with copper sulfate, sodium arsenite, Rosin Amine D acetate, Endothal, or CMU.

During treatment the plants were vigorously stirred with a glass rod for approximately 5 seconds at 10-minute intervals. At the end of the 30-minute contact period, the containers were drained, filled with tap water and drained three times to wash out the herbicide, and finally filled with tap water and placed under a 750-watt incandescent lamp maintained about a meter above the beakers on a table in the laboratory.

Six weeks following treatment, the treated plant material was placed in dissecting pans and the green plant entities, corresponding to natural fragmentation of leafy pondweed observed in the Denver area, were tabulated for each treatment. A similar procedure was followed with respect to evaluating herbicides on the pond scums except that degrees of deterioration of the sample as a whole was estimated.

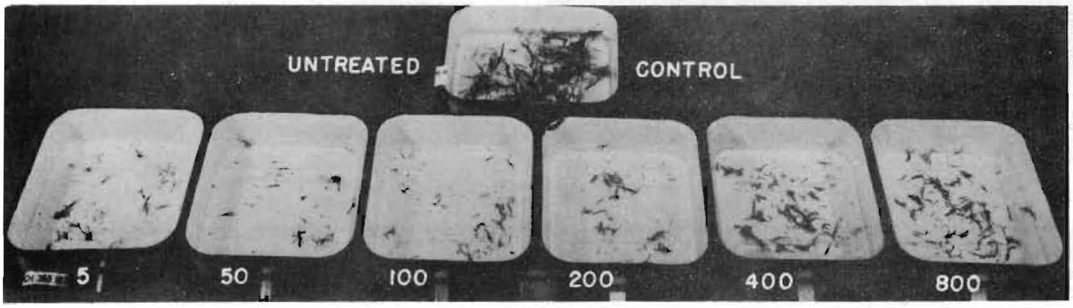
Results

When applying results obtained in a laboratory beaker test to field situations, it is necessary to remember that in the beaker test all of the excised plant parts come into contact with the aromatic solvent used. On the other hand when treatments are made on normally submersed aquatic plants in the field, the aromatic solvent apparently does not pass below the soil line in the irrigation channel bottom. Thus, the undamaged rhizomes which remain will produce new stems and leaves a short time after field treatment with aromatic solvent has been completed.

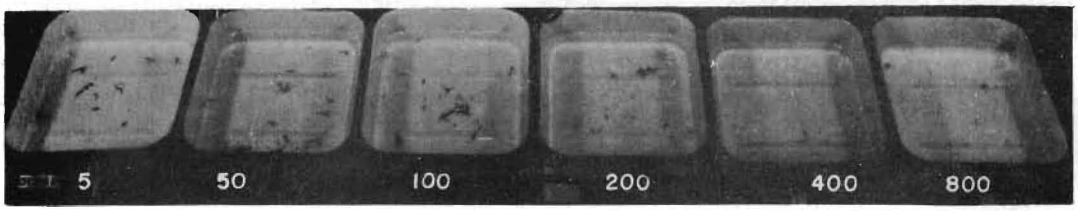
Nevertheless, from results obtained in the beaker test as illustrated in Figures 15 and 16, it is possible to obtain some indication of the degree of performance which can be expected of the contact herbicides tested when applied in the field. Excised parts of leafy pondweed and the true waterweeds (*Elodea* spp.) lend themselves especially well to the beaker test since excised parts of these plants will remain buoyant and retain their natural turgid condition for considerable periods of time. Too, both of these plants will readily produce new plants from normally quiescent lateral bud tissue. As pointed out earlier, concentrations of chemicals which are effective on one plant are not necessarily effective on other species. Accordingly, it is necessary to know the kind or kinds of species to be treated in the field if the information obtained in the laboratory is to be most effectively translated to respective field growth situations.

As shown in Table 2, monochloro-, dichloro-, and trichlorobenzenes, toluene, xylene, and trimethylbenzene emulsified in water in concentrations of 100 ppm or above gave relatively high kills of leafy pondweed. Kerosene, benzene, polychlorobenzene, and the two commercial aquatic weed killers gave less consistent kills at the same concentrations. Benzene was more effective than kerosene while the monochloro-, dichloro-, and trichloro-benzenes were more effective herbicides than was benzene. Except at the higher concentrations, polychlorobenzene was less effective. In another series, the methylated benzenes, i.e., toluene, xylene, and trimethylbenzene were more effective herbicides than was benzene with xylene giving the best results. Of special interest, too, is the fact that both copper sulfate and sodium arsenite gave more effective kills of leafy pondweed at the lower than at the higher concentrations evaluated.

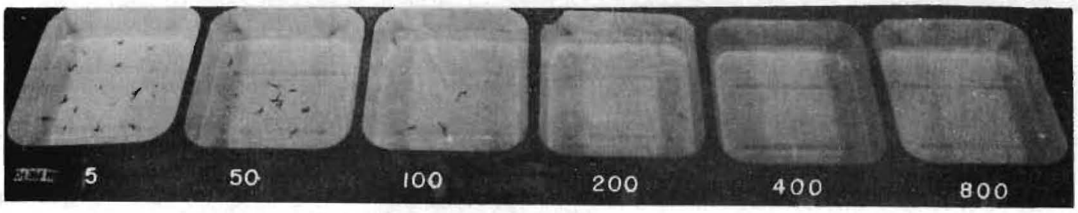
The aliphatic and aromatic solvents: emulsified kerosene, benzene, dichlorobenzene, and trichlorobenzene were effective as algaecides in concentrations ranging from 5 to 800 ppm (Table 3). At the higher concentrations copper sulfate and CMU were effective algaecides. Sodium arsenite, Rosin Amine D acetate, and Endothal, on the other hand, were not effective under the conditions of test.



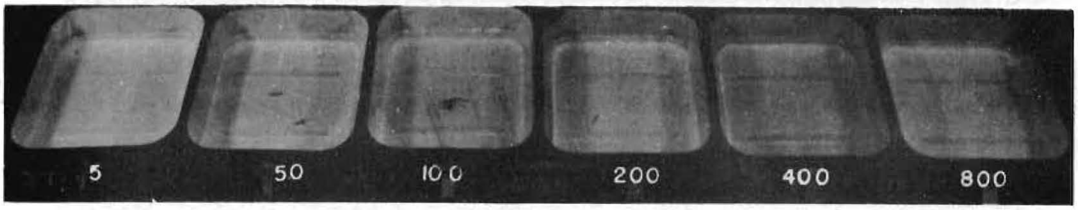
Kerosene



Benzene

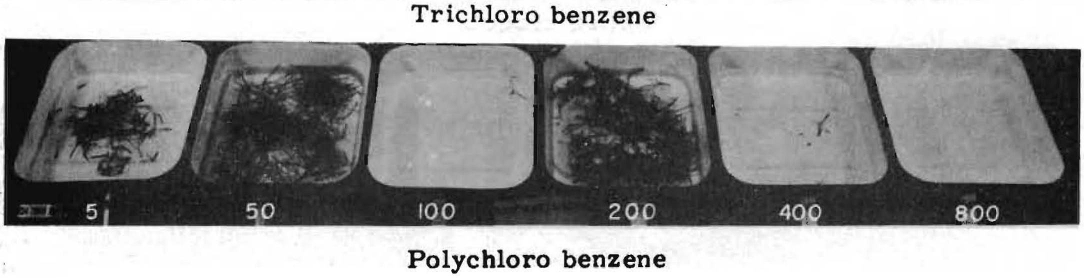


Monochloro benzene



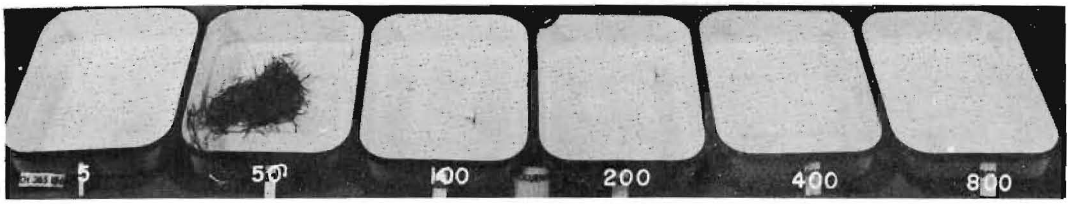
Dichloro benzene

Trichloro benzene

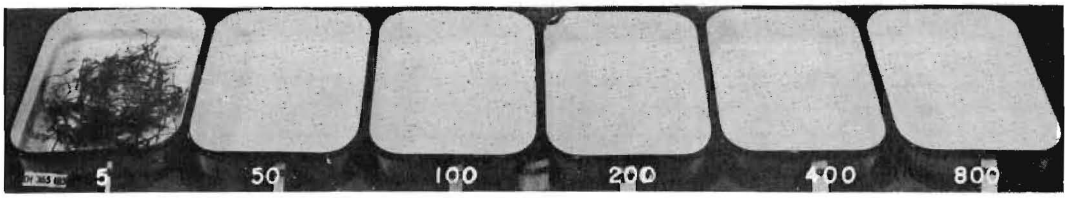


Polychloro benzene

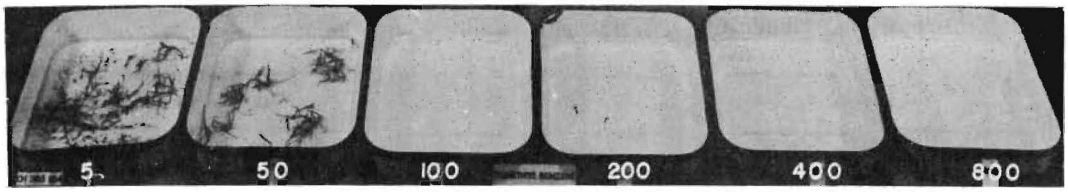
Fig. 15 Killing effect of various herbicides on volumetrically measured excised portions of leafy pondweed 6 weeks following a 30 minute submersion period of the plants. Exposure concentration in ppm shown below each pan treated.



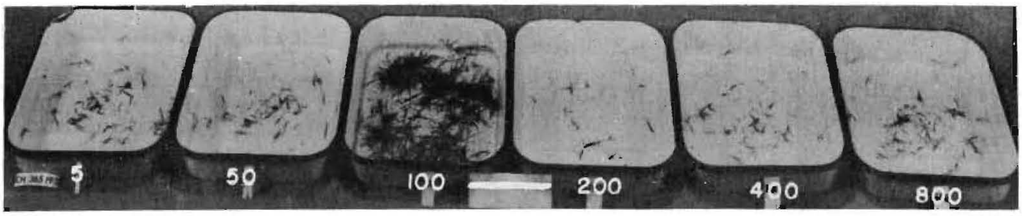
Toluene



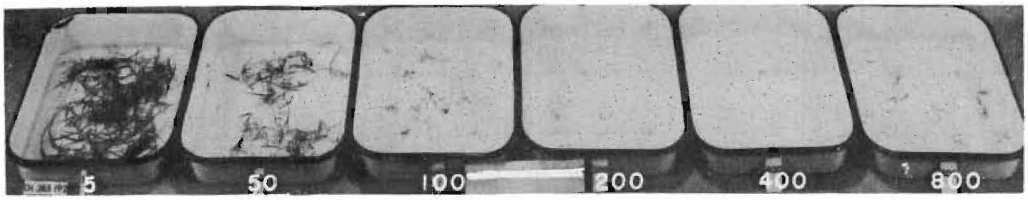
Xylene



Trimethyl benzene

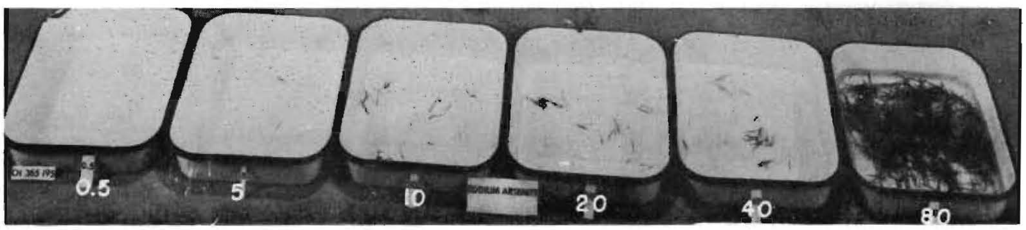


Commercial aquatic weed killer No. 1



Commercial aquatic weed killer No. 2

Copper sulfate



Sodium arsenite

Fig. 16 Killing effect of various herbicides on volumetrically measured excised portions of leafy pondweed 6 weeks following a 30 minute submersion period of the plants. Exposure concentration in ppm shown below each pan treated.

Table 2--Killing effect of selected herbicides on volumetrically measured excised portions of leafy pondweed 6 weeks following treatment*

Herbicide used	Contact time	Number of new plant entities remaining for different concentrations in ppm					
		5	50	100	200	400	800
Tap water	Untreated controls	56	48	101	75	92	41
Kerosene	30 minutes	39	22	27	33	65	76
Benzene	30 minutes	12	26	12	12	2	2
Monochlorobenzene	30 minutes	10	9	4	0	0	0
Dichlorobenzene	30 minutes	0	2	1	0	0	0
Trichlorobenzene	30 minutes	25	3	0	1	0	0
Polychlorobenzene	30 minutes	33	102	1	106	1	0
Toluene	30 minutes	6	82	5	1	0	0
Xylene	30 minutes	67	0	0	0	0	0
Trimethylbenzene	30 minutes	32	36	0	2	0	0
Commercial Weed Killer No. 1	30 minutes	33	25	77	10	34	42
Commercial Weed Killer No. 2	30 minutes	90	54	21	3	1	13
		Concentration in parts per million					
		0.5	5	10	20	40	80
Copper sulfate	6 weeks	5	9	135	213	142	155
Sodium arsenite	6 weeks	0	3	10	14	15	200

*The initial plant volume treated ranged from 8.5 to 24.0 ml and in most samples was between 12.5 and 20.0 ml.

Table 3--Killing effect of selected herbicides on a half and half mixture of the pond scums Cladophora and Spirogyra 6 weeks following treatment

Herbicide used	Contact time	Concentration in parts per million					
		5	50	100	200	400	800
		Survival 6 weeks following treatment, percent					
Tap water	Untreated controls	100	100	100	100	100	100
Kerosene	30 minutes	0	0	0	0	0	0
Benzene	30 minutes	0	0	0	0	0	0
Dichlorobenzene	30 minutes	0	0	0	0	0	0
Trichlorobenzene	30 minutes	0	0	0	0	0	0
Copper sulfate	30 minutes	100	100	100	100	100	0
Sodium arsenite	30 minutes	100	100	100	100	100	100
Rosin Amine D acetate	30 minutes	100	100	100	100	100	100
Endothal	30 minutes	100	100	100	100	100	100
CMU	30 minutes	100	100	100	0	0	0

Aquarium Test

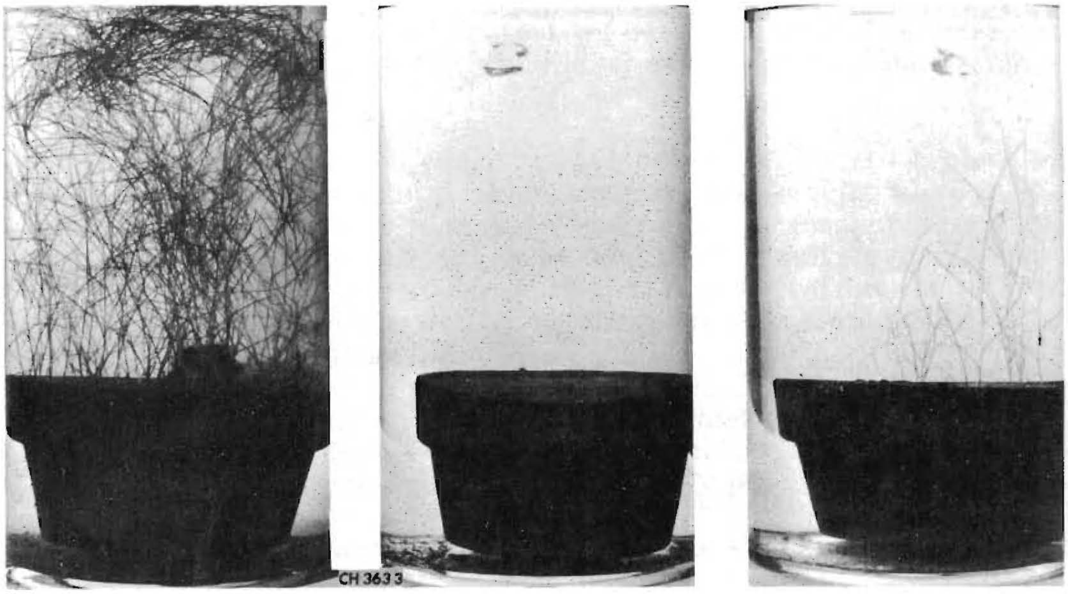
Procedure

Sago and leafy pondweed plants were rooted in soil contained in clay flower pots 6 inches in diameter and 4 inches in depth. The plant cultures were grown in the pots which were placed in large metal aquaria under 750-watt incandescent lamps that were approximately 1 meter above the water surface of the aquaria. The pots containing aquatic weeds were transferred to glass and plastic aquaria of 4- or 5-gallon capacity for treatment purposes.

Endothal was applied at concentrations ranging from 1 to 240 ppm. No emulsifier or other chemicals were used with Endothal in these herbicidal applications. When the chemical was used at short contact periods, the water was stirred at 5-minute intervals. At the end of the treatment, the aquarium was emptied, filled and rinsed three times with tap water, and finally filled with tap water to remain under the lamps for observation. From time to time, the cultures were examined in order to estimate the percent kill.

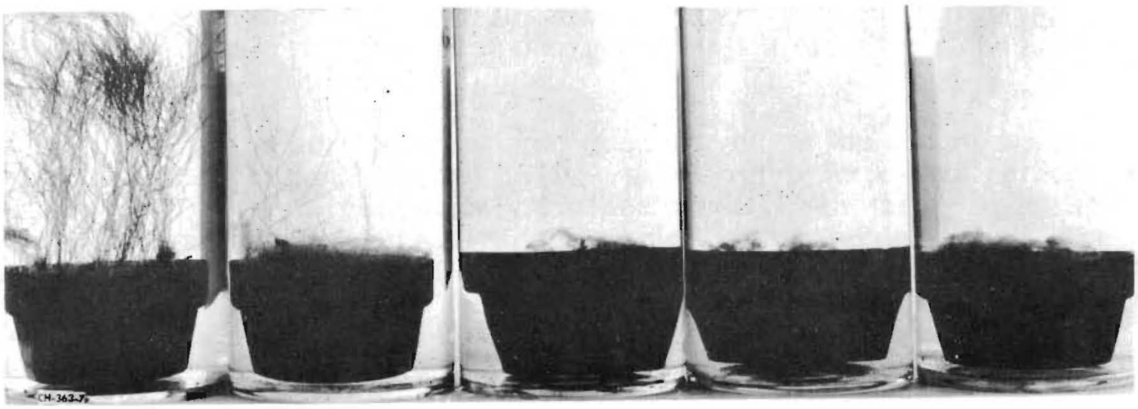
Results

The results from the use of Endothal in the aquarium test, illustrated in Figure 17, demonstrate the importance of this test for evaluating the possibilities of a contact herbicide for field use. Rooted cultures of leafy and sago pondweeds lend themselves particularly well to this test. Percent top-kill and regrowth can be estimated very readily. Also, the



Untreated control | 240 ppm | 240 ppm

Four months following exposure to this concentration for 30 min. (x 1/5)



Untreated control | 1 ppm | 2.5 ppm | 5 ppm | 10 ppm

Seven weeks following exposure to these concentrations for 3 weeks. (x 1/7)

Fig. 17 The effects of Endothal on rooted cultures of sago pondweed.

culture can be left in the aquarium for an extended period of time permitting observation as to whether underground growth has been completely killed.

Endothal gave a complete or high percentage kill (Table 4 and Figure 17) of rooted cultures of sago and leafy pondweeds when used at concentrations of 48 ppm or higher on leafy and 240 ppm on sago for 30 minutes. Longer contact periods gave excellent results even at low concentrations. When Endothal was used at concentrations of 2.5, 5, and 10 ppm for a 3-week contact time, there was a complete kill of pondweeds at all concentrations.

Excised portions of dense waterweed and pond scum were unaffected by Endothal under conditions of this test. However, good results were obtained on excised cultures of leafy pondweed.

The fact that Endothal is water soluble should make it easier to apply to an irrigation canal and the loss of chemical by volatilization or deposition would be minimal as compared to aromatic solvents. However, its possible injurious effect on crops irrigated with treated water might make its use in irrigation canals too hazardous (62).

Aromatic Solvent Spraying on Drained Versus Undrained Tanks

Procedure

Eight tanks supporting leafy pondweed growth and eight tanks supporting sago pondweed growth were used for this experiment. Half of the leafy and half of the sago pondweed tanks were drained so that water to a maximum depth of 2 inches covered the soil in the bottom of the tanks. Xylene was added to the undrained tanks by spraying at a pressure of 120 pounds per square inch (psi) so that concentrations of 400 and 800 ppm were maintained for a 30-minute period. At the end of this perioc of time the tanks were drained and filled three times, then flooded for a 5-minute period with a garden hose.

The same amount of xylene was sprayed on the drained tanks and at the same pressure of 120 psi. After a 30-minute exposure period the tanks were filled and immediately drained three times, after which they were filled and flooded for a 5-minute period with a garden hose. The same amount of xylene with 2 percent nonionic emulsifier was thus placed in the drained and undrained tanks. Six weeks later visual estimations of regrowth were made to compare effectiveness of two different methods of application when the same kind and amount of aromatic solvent per unit area had been used.

Results

With both the leafy and sago pondweed tank growths, estimated regrowth was two to four times as rapid from the treated undrained tanks

Table 4--Effect of Endothal on submersed aquatic weeds. Estimated percent kill 5 weeks to 3 months after application

Plant species treated	Rooted or excised	Concentration ppm*	Contact time	Percent kill (estimated)
Leafy pondweed (*Potamogeton foliosus*)	Excised	24	30 min	95
	Excised	60	30 min	99
	Excised	120	30 min	100
	Rooted	48	30 min	98
	Rooted	240	30 min	100
	Rooted	25	Cont'd	100
Sago pondweed (*Potamogeton pectinatus*)	Rooted	24	30 min	25
	Rooted	60	30 min	60
	Rooted	240	30 min	99
	Rooted	240	30 min	100
	Rooted	120	60 min	100
	Rooted	240	60 min	100
	Rooted	1	3 weeks	99
	Rooted	2.5	3 weeks	100
	Rooted	5	3 weeks	100
	Rooted	10	3 weeks	100
	Rooted	15	4 hours	98
	Rooted	2.5	24 hours	98
	Rooted	25	24 hours	100
	Rooted	50	Cont'd	100
Dense waterweed (*Elodea densa*)	Excised	80	30 min	0
	Excised	240	30 min	0
	Excised	400	30 min	0
Pond scum (*Cladophora* sp.)	-	1	30 min	0
	-	10	30 min	0
	-	20	30 min	0

*Based on active ingredient.
The temperature of water ranged from 75° to 80° F in these tests.

than for the treated drained tanks even though the same kind and amount of xylene had been used on both tanks. In general, it can be said that in the greenhouse experiments, regrowth was approximately twice as rapid for undrained treated tanks as it was for those drained before treatment. Apparently, stem as well as leaf tissue was more effectively penetrated.

The greenhouse results suggest that aromatic solvent might be most effectively applied to irrigation systems in the field by using a technique of first gravity draining the ditch and then spraying the flaccid water plants lying on the canal bottom using a boom and moderate pressure. In those situations where it is impractical to drain a canal system or where movement of spray equipment along the bank is difficult the suggested new technique could not be used. This technique, which would put a proportionately higher concentration of the applied herbicide in contact with the plant tissue to be treated, should consist of the following steps: (a) shut off irrigation water flow and allow maximum possible gravity drainage from the ditch bottom; (b) starting preferably at the upstream end of the plot to be treated, spray methylated or chlorinated aromatic solvent, using an emulsifying agent, on the waterweeds growing in the bottom of the gravity drained ditch; (c) allow 30 minutes for absorption of chemical by water plants (normally, adequate contact time will have elapsed while treated area is being sprayed. By the time spray operator has moved back upstream, it should be time to turn water back into irrigation ditch); and (d) waste the first 5 minutes of water passing over treated area. This technique should give more lasting waterweed killing results than those currently employed without attendant injury to farm crops. Whereas present methods of placing aromatic solvent in concentrations of 450-750 ppm and depending upon the treated water to carry the herbicide to the plants is generally, from the standpoint of economics, limited to stream flows not in excess of 50-70 cubic feet per second, the method here suggested would be relatively more economical as the carrying capacity of the drained irrigation canal increased.

USE OF HERBICIDAL PELLETS IN THE CONTROL OF SUBMERSED AQUATIC WEEDS

Several chemicals, separately and in various combinations, have produced browning and defoliation of waterweed leaves, or a temporary suppression of only the top portion of the plant in irrigation ditches, but the viable rootstocks have remained as a source for rapid regrowth. Thus, it is desirable not only to destroy vegetative growth present in an irrigation channel, but also to allow an absolute minimum of fruits or seeds, lateral or winter buds, or fragmentation propagules to remain behind as a potent source for new reinfestations.

Procedure

Powders of 2, 4-D free acid, 2, 4-D sodium salt, alpha benzene hexachloride, RADA, and CMU were pelletized at a pressure of approximately 47, 100 pounds per square inch. These pellets and unpelletized sodium borate were weighed in numbered aluminum disks which in turn were placed on the submerged soil covering the bottom of water-filled tanks in which an assortment of submersed and emergent growing water plants were rooted (see Table 5).

Results

The results recorded 10 months after herbicidal pellets were placed on the inundated soil bottom of tanks in which submersed rooted aquatic plants were growing are presented in Table 5. Effects of some of the pellets used on the water plants, water cress, leafy pondweed, sago pondweed, American pondweed, and Richardson's pondweed approximately 10 months after the experiment was begun, are illustrated in Figures 18-20.

In interpreting observations on normally submersed aquatic plants, it is necessary to take into account the normal life history phenomena of the species involved. Nevertheless, it can be said that all of the herbicides evaluated, except the alpha benzene hexachloride, showed promise as effective herbicides on submersed aquatic weeds in static water situations.

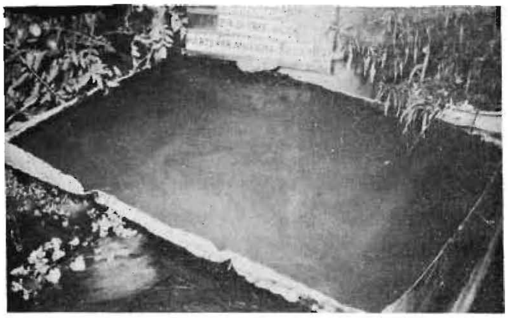
With the exception of dense waterweed, all submersed aquatic plants tested were killed with CMU concentrations of less than 10 ppm. A concentration of 10 ppm in 1 acre foot of water is equal to an application of approximately 27 pounds per acre. This chemical would appear to have extensive potential possibilities on the water hyacinth beds of the southeastern United States. The 2, 4-D free acid and sodium salt in concentrations between 75 and 150 ppm cleared the tanks of the initial vascular plant growth but permitted replacement by the pond scum, e.g., Spirogyra. Apparently with RADA, concentrations of 100 ppm or more are necessary to effectively eliminate the submersed aquatic aboveground growth. Sodium borate in concentrations varying between 342 and 643 ppm effectively eliminated aboveground submersed waterweed growth of most species tested but permitted regrowth or replacement by other species.

Table 5--Killing effect of selected herbicidal pellets on rooted pondweed growth 10 months following contact with the plants

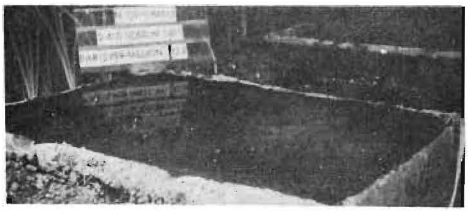
Chemical	Parts per million	Pondweed treated	Comments
Sodium borate	342	Leafy	Tank with 25% pondweed 75% cover by horned pondweed
	427	Sago	Tank clear of pondweed 100% cover by horned pondweed
	458	American	Pondweed replaced by blue-green algae
	643	Richardson's	Pondweed regrowth appears stunted
CMU (3-(p-Chlorophenyl)-1,1-dimethylurea)	7.3	Leafy	Tank clear of vegetation
	8.3	Sago	Tank clear of vegetation
	7.4	American	Tank clear of vegatation*
	9.2	Sago	Tank clear of vegetation
2,4-D sodium salt	89.0	Leafy	Pondweed replaced by Spirogyra
	76.6	Sago	Some blue-green algae present Tank clear of pondweed
	80.1	American	Tank clear of pondweed 100% cover by Spirogyra
	114.0	Richardson's	Tank clear of pondweed 100% cover by Spirogyra
	25.0	Sago	Tank clear of pondweed
2,4-D free acid	144.4	Sago	Pondweed replaced by Spirogyra
	143.6	Sago	Tank clear of pondweed
	20.0	Sago	Tank clear of pondweed
RADA (Rosin Amine D acetate)	59.3	Sago	70% regrowth
	66.3	American	100% regrowth
	62.0	Leafy	Pondweed up to 1 inch in length scattered along bottom of tank
	26.6	Sago	100% regrowth
	100.0	Leafy	100% top kill. 10% regrowth
	50.0	Leafy	100% top kill. 100% regrowth
	50.0	American	100% top kill. 100% regrowth
	100.0	Sago	98% top kill. 100% regrowth

*A backswimmer of the family Notonectidae and of the order Hemiptera swam freely in the treated tank with no apparent injury.

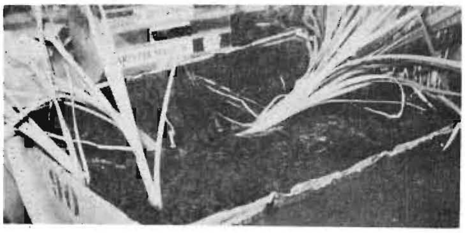
Untreated control



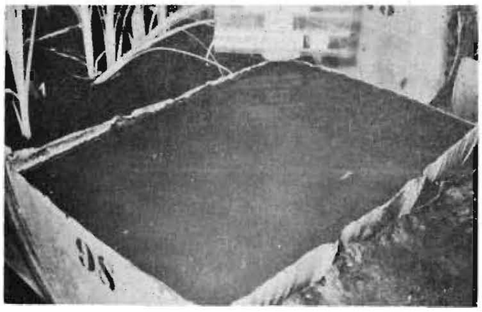
2,4-D free acid 223.7 ppm



2,4-D sodium salt 12.8 ppm



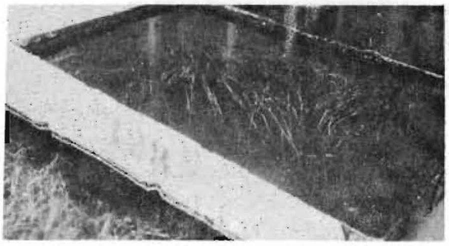
Sodium borate 736 ppm



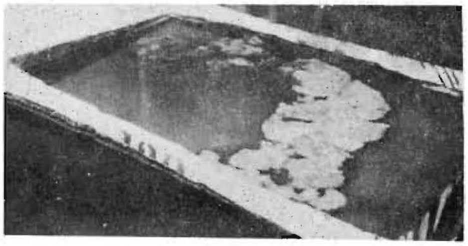
C M U 15.8 ppm

R A D A 39.9 ppm

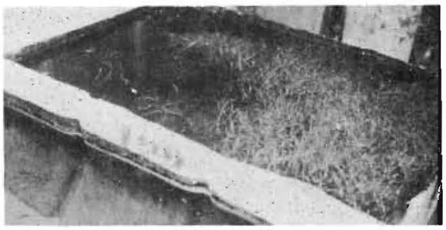
True water cress



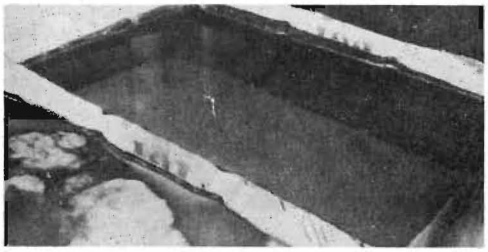
Untreated control



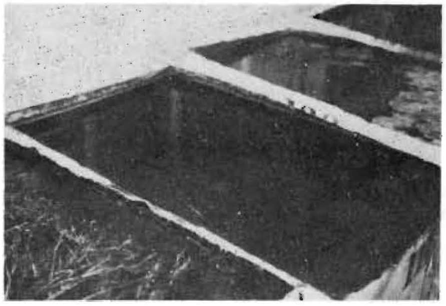
2,4-D sodium salt 89.0 ppm



Sodium borate 342 ppm



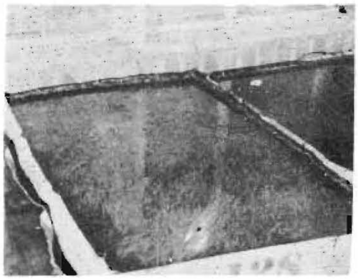
C M U 7.3 ppm



R A D A 62.0 ppm

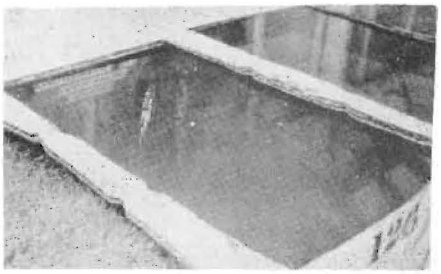
Leafy pondweed

Fig. 18 Use of herbicidal pellets in the control of True water cress and leafy pondweed. Photographs show tanks 10 months after herbicidal pellets were placed on the inundated soil bottom in which submersed rooted aquatic plants were growing.

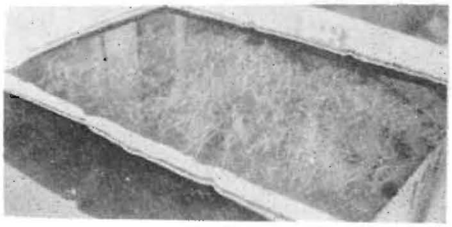


Untreated control

2,4-D free acid 144.4 ppm

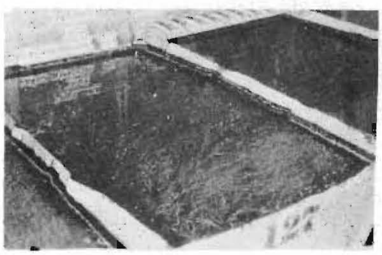


2.4-D sodium salt 76.6 ppm



Sodium borate 427 ppm

C M U 8.3 ppm

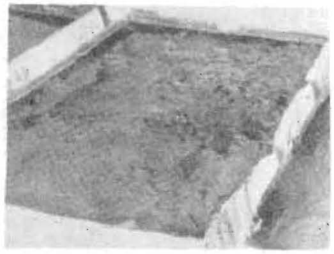


R A D A 59.3 ppm

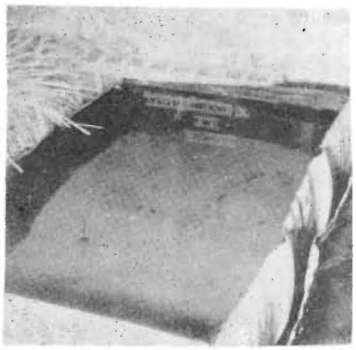
Sago pondweed

Untreated control

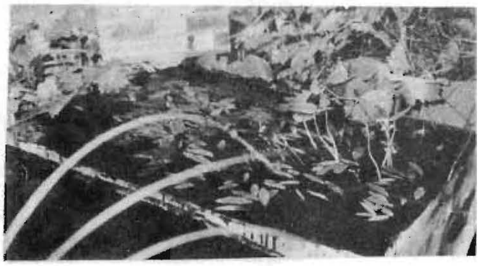
2,4-D sodium salt 80.1 ppm



Sodium borate 458 ppm



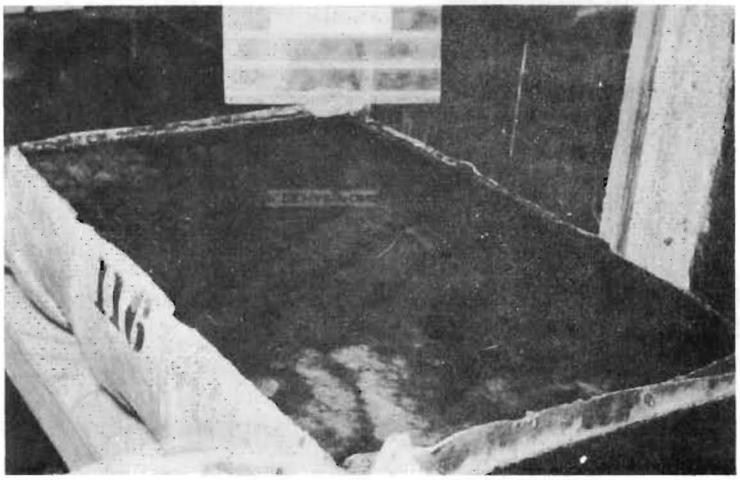
C M U 7.4 ppm



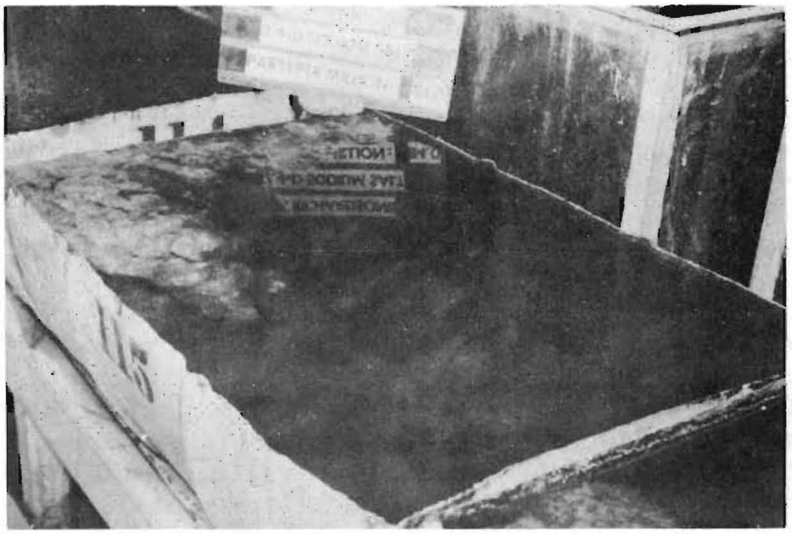
R A D A 66.3 ppm

American pondweed

Fig. 19 Use of herbicidal pellets in the control of Sago pondweed and American pondweed. Photographs show tanks 10 months after herbicidal pellets were planted on the inundated soil bottom in which submersed rooted aquatic plants were growing.



Untreated control



2, 4-D sodium salt 114.0 ppm

Sodium borate 643 ppm

Richardson's pondweed

Fig. 20 Use of herbicidal pellets in the control of Richardson's pondweed. Photographs show tanks 10 months after herbicidal pellets were planted on the inundated soil bottom in which submersed rooted aquatic plants were growing.

HERBICIDAL TREATMENT ON AERIAL PARTS OF PLANT MATERIALS TRANSPLANTED TO METALLIC CONTAINERS

Procedure

Most of the waterweeds, pondweeds, horned pondweed, and water star grass plants used were transplanted from the field directly to the container with as little root disturbance as possible 1 week before treatment. In some instances, tubers of gigantic sago pondweed were planted directly in the soil located in the bottom of the tank.

Approximately eighty 27-gallon, eighty 36-gallon, and ten 7-gallon metallic containers were used in this study. The larger capacity containers were prepared by cutting 55-gallon metallic drums in two crosswise or lengthwise. The smallest capacity containers were prepared by cutting 15-gallon metallic containers lengthwise. The inside of all containers was painted before use with two coats of coal-tar paint to inhibit rust formation. The exposed surface area measurements were calculated to be 380 square inches for the large round tanks and 759 square inches for the large long tanks. The small tanks were calculated to have an exposed surface area of 336 square inches. These smaller tanks were used only for the untreated controls.

Before each of the various chemical treatments was made on the normally submersed aquatic plants growing rooted in the soil in the bottom of the metallic containers, water was drained off the tanks with 1/2-inch rubber tubing. Because the soil in the bottom of the tanks was not perfectly level, small water puddles up to 2 inches in depth remained in the bottom of the planted tanks. This condition, it is believe, simulates that which would prevail when water flow is completely cut off in an irrigation ditch, i.e., complete drainage would not occur because of occasional low spots in the ditch bottom.

Aerial herbicidal application was made in each case with a 1-quart capacity, Model A, Sure Shot pneumatic sprayer. The quantity of the particular chemical used in this study was determined by computing the difference between the initial amount placed in the sprayer and the amount remaining therein after the spray application had been made. Initial air pressure in the sprayer for each spraying was 120 pounds per square inch.

When systemic herbicides were used in both first and second treatments, the summation of the two was reported as pounds per acre for that particular treatment. In like manner, when the same kind of contact herbicide was used in both first and second treatments, the summation of the two was reported as pounds per acre for that particular treatment.

In order to obtain a quantitative measurement of the effect of the various chemicals used, in several instances the living plant material remaining in the tank at the termination of the experiment was harvested, weighed fresh, oven-dried, and weighed again. This quantity of oven-dried residue remaining was compared with the oven-dried residue in the control tanks in which half the area was clipped each time an aerial herbicidal treatment was made on the experimental tanks.

Bohmont (8), and Grigsby, Churchill, Hamner and Carlson (29) have pointed out the fact that herbicidal action of 2, 4-D and 2, 4, 5-T are related to the actual acid equivalent of the formulation. Accordingly, the amount of phenoxyacetic acid derivative used on these various tanks was calculated on an acid equivalent pound-per-acre and gallon-per-acre basis. Contact herbicides used were also calculated on a pound-per-acre and gallon-per-acre basis.

The spray was applied on the flaccid aquatic plants which, in the absence of the usual water supporting medium, were lying on the soil in which they were rooted. The sprayed plants normally submerged were allowed to remain lying on the soil at the bottom of the tank for a period varying from 2 to 6 hours following spraying, to allow the herbicides to penetrate the plant tissues. In the report this is recorded as exposure time. At the end of this time, the tanks with the sprayed plants were filled with tap water and drained immediately. This operation was repeated twice after which the tanks were filled a third time with tap water and flooded for 5 minutes. Water was drained off of the untreated control tanks and the plants growing therein were subjected to the same 2- to 6-hour desiccation as the chemically sprayed tanks, the only difference being that no chemical was applied.

It should be noted that this same uniform technique was used even when using contact chemicals in aqueous solution, e.g., copper sulfate, sodium arsenite, methylated and/or chlorinated aromatic solvents, et cetera.

It was believed that by filling and siphoning off the water in the tanks twice and then filling and flooding for 5 minutes, any herbicide which had not entered the plant in the 2- to 6-hour exposure period would be washed out of the tank; thus, any effects observed after treatment could be attributed to entry of the chemicals into the flaccid plants during the exposure time when the water was out of the tank. This washing effect was thought to simulate the washing effect which would occur when water is turned back into an irrigation ditch where rooted aquatic weeds have been sprayed, using a technique similar to the one described for the rooted aquatic weeds growing in the tanks.

In some instances, a contact herbicide was applied 24 hours after a systemic herbicide had been used. In other experiments, several weeks elapsed between the two or three separate treatment applications. In each case, one-half of the plants in the control tanks was undisturbed, and the remaining half was clipped to the ground with household scissors. Thus, a comparison could be made between no disturbance, clipping, and chemical treatment.

At the termination of the experiment 6 weeks following herbicidal application, the water was drained off and an estimate made of the percentage of the soil area in the bottom of the tank supporting green plant growth of the initial species present in the tank. The soil in the bottom of the tanks was examined for the presence of living underground propagules. From this physical examination estimated percentage survival was determined.

Results

Results of aerial herbicidal treatments in the greenhouse on waterweed, pondweeds, horned pondweed, and water star grass are presented in Tables 6-12.

Systemic herbicidal treatment (with 2, 4-D) followed 24 hours later with contact herbicides seemed to be less effective in control or eradication than the 2, 4-D treatment without any following contact herbicide. Applications of 2, 4-D made in repeated treatments 6 weeks apart appeared to be more effective than when the same quantity was applied as a single treatment. In general, it appeared advisable to administer two-thirds of the total quantity of herbicide in the first application followed by application of the remaining one-third 6 weeks later.

In general, the following physical phenomena were observed for the aquatic vascular plants treated with 2, 4-D: (a) 1 week after treatment, stems and leaves showed pronounced curvatures; (b) 4 weeks after treatment, chlorophyll depletion was apparent with most leaves and stems brown and apparently dead; and (c) 6 weeks after treatment, regrowth, if any, developed from latent propagules, e.g., buds, seeds, etc.

Some survival occurred in treated tanks containing American, gigantic sago, and Richardson's pondweeds even when relatively large quantities of 2, 4-D were used. Western waterweed, horned and leafy pondweeds and water star grass were much more susceptible but pond scum and stonewort were not affected by any rate of 2, 4-D. In the laboratory it has been determined that applications of 2, 4-D simulating spray operations along gravity drained canal bottoms at rates varying with species predominating can effectively kill a large percentage of underground water plant propagules with concentrations in general varying between 5 and 15 pounds to the acre (acid equivalent basis). However, as much as 33 pounds per acre were required to eliminate the most resistant species.

Following is a compilation of what appears to be the optimum approximate amount of 2, 4-D as the isopropyl ester needed to bring about best control or eradication of the plants evaluated with single treatments:

Table 6--Estimated survival in greenhouse treated western waterweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	13.4	0
	11.3	0
	8.4	0
	5.9	0
	5.1	0
95% coal-tar naphtha solvent	*493.2	0
	0.0	100

*Gallons per acre.

Table 7--Estimated survival in greenhouse treated American pondweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	26.2	0
	23.1	0
	21.6	0
	18.7	10
	16.8	5
	13.6	5
	11.8	5
	11.4	5
	9.4	15
	9.2	25
Alpha benzene hexachloride	1,277.6	5
Rosin amine D acetate	658.1	0
Anhydrous copper sulfate	492.0	40
10% 3-(p-chlorophenyl)-1, 1-dimethylurea	21.5	0
Maleic hydrazide	16.8	100
	0.0	100

Table 8--Estimated survival in greenhouse treated gigantic sago pondweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	38.4	0
	38.1	0
	33.1	0
	22.5	5
	21.6	5
	20.4	5
	17.5	5
	16.6	10
	15.7	10
	13.6	5
	11.4	20
	11.3	15
	10.8	5
	10.6	20
	8.1	10
	5.5	30
Anhydrous copper sulfate	333.7	100
	196.6	100
Sodium arsenite	517.1	25
Sodium pentachlorophenate	432.2	0
95% coal-tar naphtha solvent	*577.1	100
	0.0	100

*Gallons per acre.

Table 9--Estimated survival in greenhouse treated leafy pondweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	8.2	0
	6.9	0
	5.6	5
	4.9	0
	3.5	85
Rosin amine D acetate	307.2	0
Sodium pentachlorophenate	154.4	0
Anhydrous copper sulfate	195.0	100
Maleic hydrazide	248.1	100
10% 3-(p-chlorophenyl)-1, 1-dimethylurea	36.1	100
Xylene	*253.3	100
95% coal-tar naphtha solvent	*159.4	100
	0.0	100

*Gallons per acre.

Table 10--Estimated survival in greenhouse treated Richardson's pondweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	54.1	0
	41.7	0
	37.5	0
	27.1	5
	22.6	10
	15.1	15
	12.0	0
	11.3	5
	9.3	0
	7.1	0
	6.1	50
	5.9	90
	5.5	60
	4.6	70
Sodium chlorate	2,507.1	0
	0.0	100

Table 11--Estimated survival in greenhouse treated horned pondweed plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	13.5	0
	12.4	0
	10.8	0
	7.2	0
Alpha benzene hexachloride	806.4	0
Anhydrous copper sulfate	447.0	100
Sodium arsenite	356.1	40
Sodium trichloracetate	328.5	0
	0.0	100

Table 12--Estimated survival in greenhouse treated water star grass plants 6 weeks following herbicidal application

Herbicide applied	Rate per acre	Survival
	Pounds	Percent
2,4-D, isopropyl ester	27.5	0
	19.1	0
	8.6	0
	4.6	0
Sodium chlorate	1,175.5	0
95% coal-tar naphtha solvent	*441.0	0
	0.0	100

*Gallons per acre.

Water plant	Lb per acre of 2, 4-D	Percent survival 6 weeks after application
Western waterweed	5	0
American pondweed	12	5
Horsetail moss (Sago pondweed)	15	5 - 10
Leafy pondweed	5	0 - 5
Richardson's pondweed	7	0 - 15
Horned pondweed	7 or less	0
Water star grass	5 or less	0

Apparently, 2, 4-D killed the aboveground vegetative growth present at the time of tank treatments. The survival, present at the termination of the experiment, appears to have come from latent bud propagules or seeds which had not started growth at the time of aerial herbicidal treatment.

As shown in Tables 7-12, copper sulfate, sodium arsenite, and maleic hydrazide were not effective as herbicides in the concentrations and with the techniques used in these experiments. Sodium chlorate and sodium trichloracetate, on the other hand, were effective in suppressing aboveground growth.

This work suggests a new technique for applying phenoxyacetic acid compounds on submerged waterweeds growing in irrigation ditches (61, 62) that appears sufficiently promising to justify further investigation in the laboratory and the field to determine its effectiveness under various conditions and its economic practicability. This method consists of the following steps: (a) shut off irrigation water flow and allow maximum possible gravity drainage to obtain in ditch bottom; (b) apply aerial herbicidal spray of 2, 4-D using a wetting agent, or methylated or chlorinated aromatic solvent, using an emulsifying agent on the waterweeds growing in the bottom or along the banks of the gravity drained ditch; (c) allow 2 to 6 hours for absorption of chemical by water plants; (d) turn water back into irrigation ditch; and (e) waste the first 5 minutes of water flow passing over the treated area.

USE OF WATERWEEDS AS FERTILIZER

Procedure

One possibility of defraying part of the cost of mechanical control of aquatic weeds centers around the use of harvested aquatic weeds as green manure to fertilize nearby farm lands. To investigate this possibility an exploratory test was made in which sago pondweed was harvested from the Federal Center lake. The plant material was examined and hand processed to remove other plants, e.g., leafy pondweed growing in association with the sago pondweeds, and was thoroughly rinsed in tap water to remove any soil attached to the rhizomes. The fresh material was placed in wire baskets in a drying oven maintained at 62° C and left until constant weight was obtained. The dried plant material was then removed from the drying oven and pulverized with a Quaker City food pulverizing mill. This pulverized sago pondweed was thoroughly mixed with graded Ottawa sand in the proportion of 936 g of pulverized pondweed to 9,750 g of the sand. It should be mentioned that Ottawa sand is water washed and devoid of soluble salts or organic matter.

Four tomato plants of uniform vigor and size, growing in 4-inch diameter greenhouse clay pots, were selected for this study. All of the plants were removed from their pots with soil intact and the soil was carefully washed off of the roots of two of them. The tomato plants were planted in wooden boxes 11 inches long, 9 inches wide, and 4-1/2 inches deep. One of the tomato plants with soil intact from the 4-inch pot was placed in a box containing only Ottawa sand. The other plant with soil intact was placed in a box containing the mixture of Ottawa sand and dried pulverized sago pondweed. Similarly, one of the tomato plants with soil removed was placed in a box containing only Ottawa sand and the other plant with soil removed was placed in a box containing the mixture of Ottawa sand and dried pulverized sago pondweed plants. The plants were placed on a table in the greenhouse and daily watered for 100 days after which a comparison was made between the weight and vigor of plants.

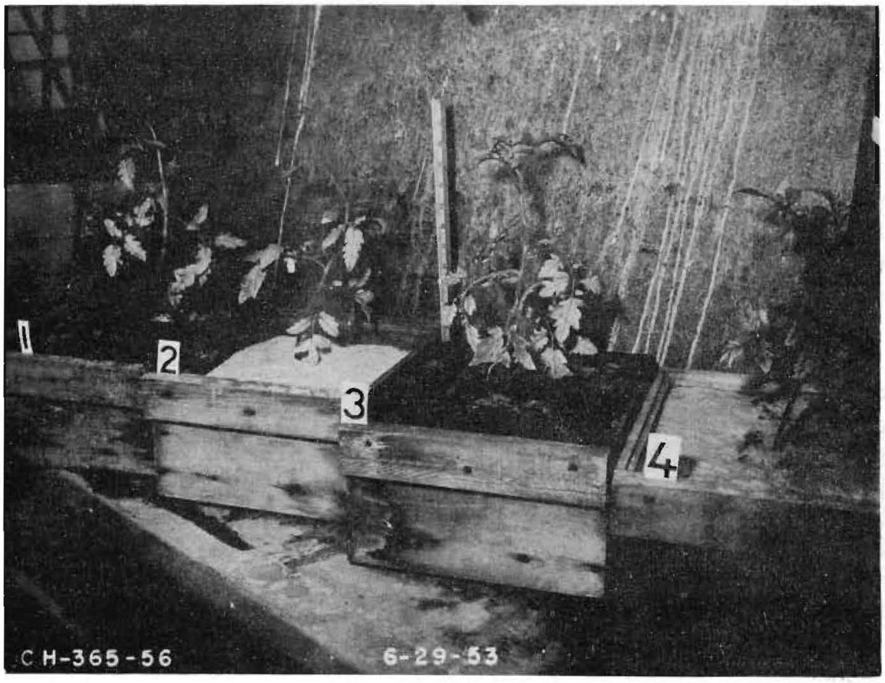
Results

Results of the exploratory test with sago pondweed as fertilizer are recorded in Table 13 and illustrated in Figure 21. In Figure 21 the plant in Box 1 is growing with soil intact, pulverized pondweed and sand, Box 2 has soil intact and sand, Box 3 has pulverized pondweed and sand and Box 4 has sand only. Vigor of the plants at the beginning of the experiment is shown at the top of Figure 21.

Table 13--Effect of pulverized sago pondweed used as fertilizer on growth of tomato plants

Plant weight, g	Growing media			
	Roots with soil intact pondweed sand	Roots with soil intact sand	Pondweed sand	Sand
Fresh	104.1	16.9	54.6	20.0
Oven-dry	14.7	3.6	8.6	2.4

At the time of harvest (Figure 21B) the two tomato plants growing in media containing pulverized pondweed had decidedly greener leaves than their counterparts growing in similar media but lacking the pulverized pondweed. The plants adjusted readily to new growth even after the



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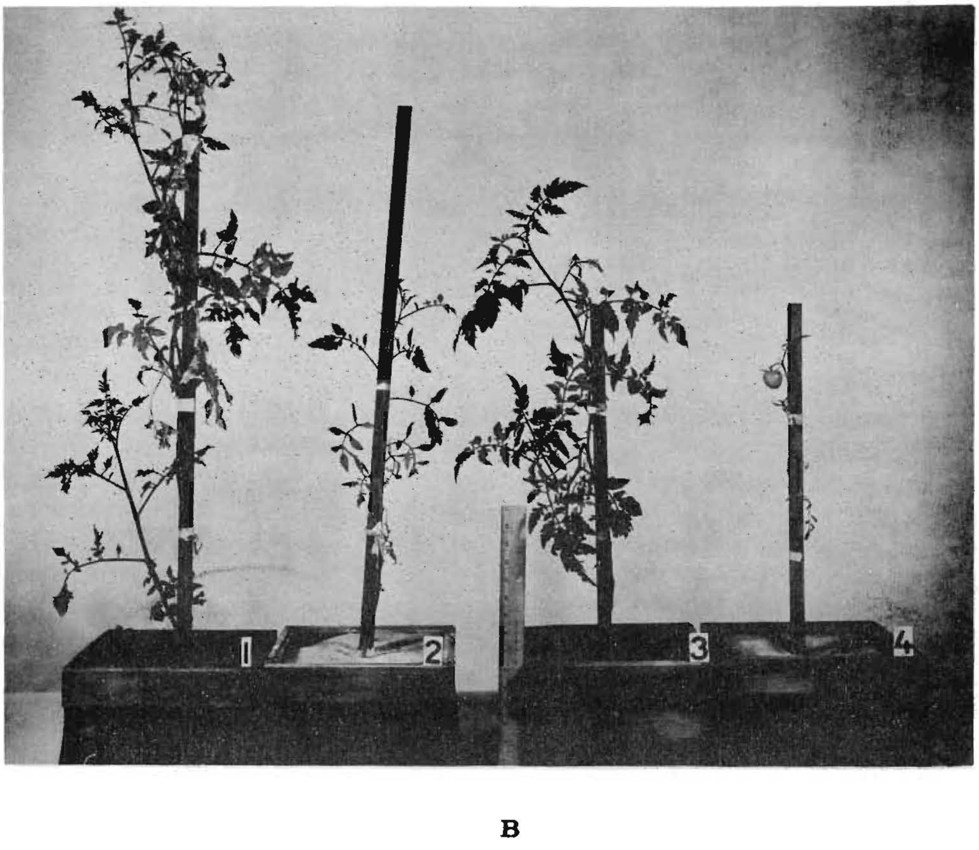


B

Fig. 21 Fertilization effect of sago pondweed on Chalk Early Jewell tomatoes. A, Initial planting of Chalk Early Jewell tomatoes; B, Comparative vigor of tomato plants after 14 weeks of growth. See text for further explanation.

soil had been removed from the roots and the plants were placed in the new growth media.

Depending upon whether initial soil from the 4-inch pots was intact or was removed, the fresh weight (Table 13) of the tomato plants growing in the media containing pulverized pondweed was about six times and three times that of their counterparts growing in similar media but without the pulverized pondweed. Oven-dry weights were about four times as great for the plants growing in media containing pulverized pondweed as they were for those plants growing in the absence of the same. Although very limited, the results of this exploratory test appear to justify further study of the possibility that unprocessed pondweed plants might be used to advantage as green manure on adjacent farm properties to help defray the cost of mechanical removal from irrigation waterways.

SUMMARY

The purpose of these investigations mainly revolves around the desire to restore insofar as practicable the originally designed carrying capacity of irrigation water distribution systems. Much of the information contained herein should be of value, too, in recreational areas where water plants may be a nuisance. In order that field waterweed control might be more thoroughly understood and its various aspects more properly evaluated, investigations were conducted along diverse phases of the problem. This, it was believed, would permit possible control measures evolved from the study to be considered in better perspective.

Plant Migration and Growth Competition

Of the two apparently useful submersed plant competitors, needle spike rush migrated in a season's growth about twice as far as dwarf arrowhead. Leafy and sago pondweeds migrated only half as fast as dwarf arrowhead.

Both needle spike rush and dwarf arrowhead appeared to be desirable growth competitors for the ranker growing pondweeds.

Pond scum effectively epiphytized leafy pondweed killing it back to the water submersed soil line a few weeks following the initial observable infestation.

Response to Environmental Conditions

Results of one test showed that leafy pondweed apparently will remain viable as long as the soil in which it grows remains moist.

Field observations indicated that leafy pondweed is more shade tolerant than its frequent field associate, gigantic sago pondweed.

Chemical Control

On metallic tanks, the vinyl-resin antifouling paint was most resistant, of the paint coatings evaluated, to the fouling action of algae.

Secretion of calcite on leaf surfaces by leafy pondweed brought about temporary control of the plant.

Chlorinated and methylated benzenes were more effective herbicides than was benzene. In general, the toxicity of methylated benzene compounds to leafy pondweed increased in proportion to the methylation.

Regrowth of aromatic solvent treated plants was approximately twice as rapid in undrained tanks as in those drained before treatment.

Endothal at less than 10 ppm concentration for a 3-week contact period was found to be an effective contact herbicide for controlling rooted cultures of sago pondweed.

With the exception of dense waterweed, all submersed aquatic plants tested were killed with CMU concentrations of less than 10 ppm over a continued contact period.

The sodium salt and free acid formulations of 2, 4-D used as pellets in concentrations of 25 ppm active ingredient basis were effective herbicides for controlling rooted cultures of leafy and sago pondweed.

Applications of 2, 4-D simulating spray operations along gravity drained canal bottoms, at rates varying with species predominating, effectively killed underground water plant propagules with rates in general varying between 5 and 15 pounds to the acre (acid equivalent basis).

Use of Waterweeds as Fertilizer

One exploratory test suggested the possibility that unprocessed pondweed plants might be used to advantage as green manure on farm properties to help defray cost of weed removal from irrigation waterways.

EMERGENT AQUATIC WEEDS

PLANT MIGRATION

Procedure

The initial plantings of broad- and narrow-leaved cattails, and ripgut grass, are described in a previous section under Submersed Waterweeds, Plant Migration, page 15.

Results

Ripgut grass which was planted in narrow bands across a canal that was 13 feet wide and varied in cross-section depth from a few inches to 4 feet grew vigorously after 1 year in water 12 inches deep or less. It did not survive in deeper water.

Narrow-leaved cattail from a clump 8 inches in diameter migrated 3 feet 9 inches in 1 year and produced 30 new plants in addition to those arising from the planted lateral or "winter" buds.

Broad-leaved cattail migrated 10 feet and produced 16 new plants in addition to those arising from the planted lateral or "winter" buds. Thus, broad-leaved cattail migrated about twice as far as narrow-leaved but produced only about half as many plants in a season's growth.

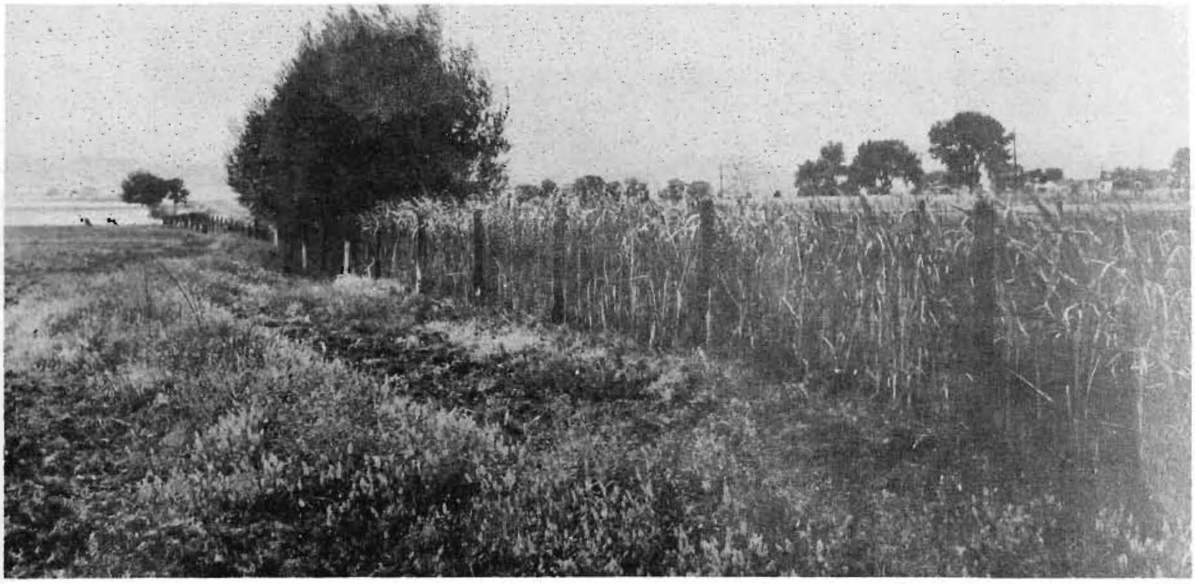
CONTROL OF BROAD-LEAVED CATTAIL BY CATTLE GRAZING

Procedure

For five consecutive growing seasons, a fenced area of pasture between 5 and 6 acres in size has been grazed intermittently. In 1948, 1949, and 1952, grazing by cattle on the area was rather intensive. In the 1950 and 1951 growing seasons, cattle grazing on the area was prohibited. Because a part of the pasture, normally heavily infested with broad-leaved cattail, had a fence line running through it, a contrast of cattail growth in the pasture area could thus be made between years in which heavy grazing occurred and the two consecutive growing seasons when the area was protected from domestic grazing animals.

Results

Grazing by one to two milch cows per acre effectively controlled growth of the broad-leaved cattail in the grazed area during 1948 and 1949 In 1950 and 1951, when domestic animal grazing was prohibited, there was considerable reinvasion by broad-leaved cattail, particularly in the second consecutive season in which grazing was prohibited. Cattail reinvasion in this instance came from the continuously ungrazed side of the fence (Figure 22).



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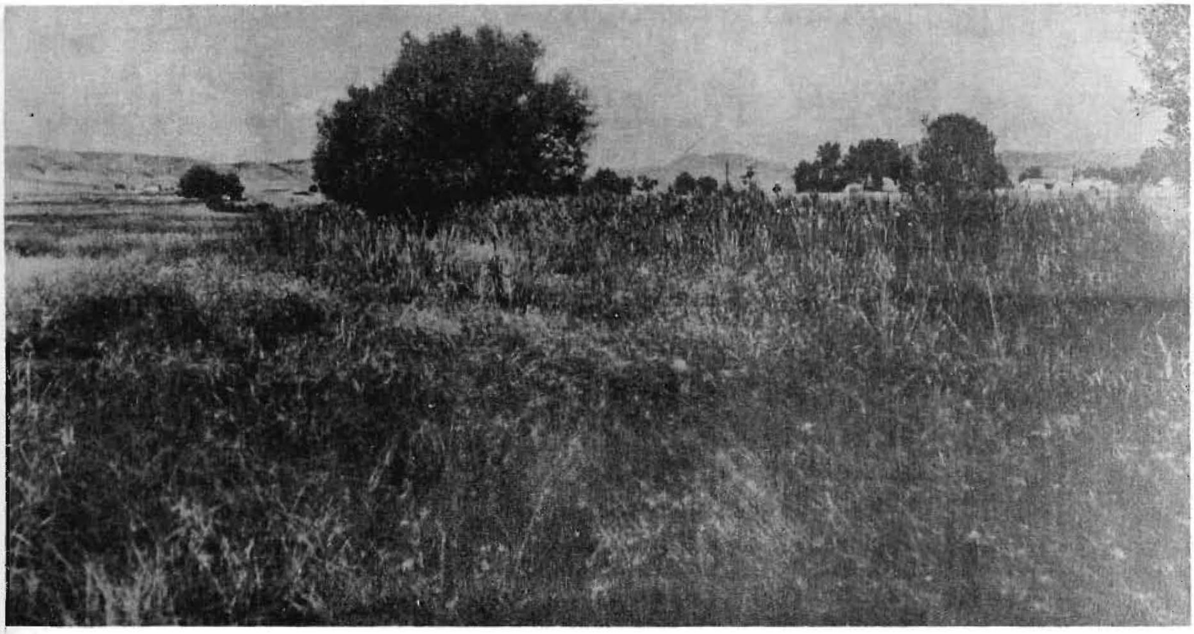


B

Fig. 22 Effect of intensified grazing on growth control of broad-leaved cattail. A. Heavily grazed by cattle. B. Reinvasion of broad-leaved cattail in same area as in A when grazing is prohibited.

The combination of eating the young cattail shoots and mechanical injury to the plants by the hoofs of the grazing cattle was sufficient to keep down the growth. It is believed that the same control observed here could be accomplished on other farm properties where broad-leaved cattail infestation is interfering with normal agricultural practices. Cattle, horses, and hogs are known (47) to graze eagerly on marsh growth, hogs being particularly destructive to tuberous or succulent rooted plants of marsh areas.

EFFECT OF WATER DEPTH ON GROWTH OF EMERGENT AQUATIC PLANTS

A number of aquatic plants appear to be able to grow rooted in environments subjected to fluctuating water lines. Leafy and American pondweeds, water cress, and water sedge are examples of plants in this category which grow at the Federal Center greenhouses. Some aquatic plants, however, are unable to survive wide fluctuations in water depth. Cattails and marsh spike rush are examples of plants in the latter category.

Procedure

In this experiment, marsh spike rush, a lake shore and stream bank plant, was transplanted with as little root disturbance as possible into buckets of 5-gallon capacity in such a manner that in two buckets the water depth above the soil line was approximately 1 inch. In two other buckets, the water depth above the soil line was approximately 10 inches.

Results and Discussion

As shown in Figure 23, marsh spike rush was controlled and even eradicated by submersing for 30 days with about 10 inches of water. As was pointed out earlier, ripgut grass failed to survive in the migration test where water depth in the canal was greater than 12 inches.

It was noted in the Summer of 1952 that when the water depth of the Federal Center lake was lowered approximately 12 inches, the broad-leaved cattail growing in a wide band area immediately off the shore line of the lake turned brown and the tops died. It appeared from this observation that lowering the water line of a lake or body of water in those areas where inadequate or no subsurface irrigation exists, can bring about a kill back or permanent kill of broad-leaved cattail, depending upon the length of time and time of growing season the water can be lowered.

Maximum water depth in which rooted emergent aquatic plants are growing appears to be a definite restricting environmental factor which limits growth locale for any particular plant. Marsh spike rush and ripgut grass apparently can be controlled or eradicated by submersing these normally lake shore or stream bank growths for 30 days with

1-29-52

2-29-52

Fig. 23 Effect of water depth on growth of marsh spike rush. Water depth in bucket No. 1011 and alternate approximately 10 inches. Water depth in bucket No. 1007 and alternate approximately 1 inch.

10 and over 12 inches of water, respectively. Where applicable, this work suggests the possibility of controlling these two plants, as well as other emergent aquatics, by raising the water depth for the necessary period of time in the areas where undesired plant growth occurs.

EFFECT OF NIGROSINE DYE ON GROWTH OF BROAD-LEAVED CATTAIL BUDS

Procedure

Lateral buds of broad-leaved cattail were placed in soil in the bottom of tanks containing 5 ppm of nigrosine dye for a period of 9 consecutive weeks. At the end of 1 day, 3 weeks, 6 weeks, and 9 weeks, dye concentrations in the samples were determined with the Coleman Universal spectrophotometer.

Results

Measurements on the Coleman Universal spectrophotometer showed concentrations to be present as indicated in Table 14. It can be seen that the dye rapidly settled out of the water to the sides and bottom in the treated tanks. The dye was accordingly considered to be ineffective. It will be necessary, therefore, to use a different light-inhibiting substance, e.g., activated carbon or other aniline dyes, if the retarding effect of lack or deficiency of light on cattail new growth is to be determined.

Table 14--Decrease in concentration of nigrosine dye placed in a tank planted with lateral buds of broad-leaved cattail

Initial ppm	After 1 day ppm	After 3 weeks ppm	After 6 weeks ppm	After 9 weeks ppm
5.0	4.3	1.2	0.4	0.6

HERBICIDAL TREATMENT ON AERIAL PARTS OF PLANTS TRANSPLANTED TO METALLIC CONTAINERS

Procedure

Aerial herbicidal treatment techniques in the greenhouse on water cress, water hyacinth, parrot's feather, water sedge, cattails, and salt cedars were similar to those reported for the submersed aquatic plants (page 31) except that when spraying the emergent aquatics, the tanks in which the plants were growing were not drained.

Water utilization was determined by measuring the quantity of water necessary to refill the tank, deducting the amount lost through evaporation.

Carbohydrate determination procedure is similar to that discussed for cattails (see page 55). The treatments are outlined in Tables 15, 16, 17, 18, 19, and 20.

Results

In this investigation, water utilization of broad-leaved cattail was decreased considerably for at least 8 days immediately following treatment with herbicidal concentrations of 2,4-D (Table 15). Maleic hydrazide applications caused much less reduction in water utilization by the cattails. Both true water cress and parrot's feather were killed with 3 pounds of 2,4-D per acre. Narrow-leaved cattail required approximately 6 pounds of 2,4-D per acre (Table 19). Broad-leaved cattail and water hyacinth required about 9-12 pounds of 2,4-D per acre for complete kill (Tables 20 and 16). Ripgut grass and Oregon sugar grass were affected more by the 2,4-D acid-TBP-kerosene formulations that other formulations, requiring about 16 and 34 pounds, respectively, of 2,4-D per acre for satisfactory kill (Tables 17 and 18). Presence of tributyl phosphate and kerosene did not appear to decrease the effectiveness of the 2,4-D present in the mixture sprayed on Oregon sugar grass. In Tables 19 and 20 it will be noted that when approximately 13 pounds of the sodium salt of 2,4-D was sprayed on narrow- and broad-leaved cattails with no wetting agent present, little or no carbohydrate reduction in food reserves occurred. The primary spray problem with all treated emergents was one of penetrating the thick cuticle. Once this was accomplished, 2,4-D in the herbicides appreciably decreased the carbohydrate root reserves.

In the control of practically all emergent aquatic plants it is believed that two-thirds of the recommended dosage should be administered with the first herbicidal application. The remaining one-third should be applied when regrowth reaches the proper height as discussed later. Following is a compilation of what appears to be the optimum approximate total amount of 2,4-D needed to bring about consistently good results in controlling or eradicating the plants evaluated. The herbicide was applied as two treatments (two-thirds and one-third of the total per application) per growing season:

Table 15--Comparison of water utilization by treated and untreated broad- and narrow-leaved cattail plants over an 8-day period

Plant species treated	Treatment	Initial shoot length cm	Measured water use per green plant in milliliters: For 8 days	Measured water use per green plant in milliliters: For 1 day
Narrow-leaved cattail *Typha angustifolia* L.	Maleic hydrazide 65 pounds per acre	131	639	80
	None	139	778	97
Broad-leaved cattail *Typha latifolia* L.	Maleic hydrazide 80 pounds per acre	140	256	32
	2,4-D, sodium salt 63 pounds per acre	137	120	15
	None	143	798	100

Table 16--Estimated survival in greenhouse treated water hyacinth plants 6 weeks following second herbicidal application

Herbicide applied	Rate per acre*	Survival
	Pounds	Percent
2,4-D, isopropyl ester	36.1	0
	33.0	0
	28.7	0
	28.3	0
	26.9	0
	21.6	10
	18.2	5
	11.5	15
	0.0	100

*Rate expressed on acid equivalent basis.

Table 17--Carbohydrate root reserve reduction and estimated survival in greenhouse treated water sedge ("Ripgut grass") plants 6 weeks following second herbicidal application

Herbicidal compound	Rate per acre*	Carbohydrates	Survival
	Pounds	Percent	Percent
2,4-D, isopropyl ester	43.4	17.8	25
amine salt	35.5	24.3	10
sodium salt	21.3	11.2	35
acid, TBP, kerosene	16.4	31.3	15
micronized	12.0	14.3	90
isopropyl ester	5.3	19.0	90
isopropyl ester	4.0	25.8	90
2,4,5-T, isopropyl ester	44.7	24.5	20
Maleic hydrazide	15.6	26.0	100
Untreated control	0.0	45.9	100

*Rate given on basis of acid equivalent or active ingredient.

Table 18--Carbohydrate root reserve reduction and estimated survival in greenhouse treated awned sedge (Oregon "sugar grass") plants 6 weeks following second herbicidal application

Herbicidal compound	Rate per acre*	Carbohydrates	Survival
	Pounds	Percent	Percent
2,4-D, isopropyl ester	68	26.8	10
acid, TBP, kerosene	34.0	19.6	5
Untreated control	0.0	31.6	100

Table 19--Carbohydrate root reserve reduction and estimated survival in greenhouse treated narrow-leaved cattail plants 6 weeks following second herbicidal application

Herbicide applied	Rate per acre*	Carbohydrate in oven-dry roots	Survival
	Pounds	Percent	Percent
2,4-D, isopropyl ester	108.1	23.0	0
isopropyl ester	96.6	29.9	0
isopropyl ester	59.0	31.3	0
isopropyl ester	33.9	34.8	0
isopropyl ester	25.3	24.8	0
isopropyl ester	15.4	36.8	0
sodium salt	**13.7	65.5	50
sodium salt	**12.6	60.8	60
isopropyl ester	9.2	20.9	0
isopropyl ester	7.5	21.4	0
isopropyl ester	6.1	26.0	0
isopropyl ester	3.9	42.1	5
isopropyl ester	3.3	26.0	10
isopropyl ester	2.7	31.7	15
Maleic hydrazide	65.4	55.4	100
Pentachlorophenol	***712.0	60.3	75
Untreated controls	0.0	58.7	100
	0.0	43.4	100
	0.0	54.1	100

*Rate expressed as acid equivalent or active ingredient.
**Sodium salt of 2,4-D was applied with no wetting agent.
***Gallons per acre.

Table 20--Carbohydrate root reserve reduction and estimated survival in greenhouse treated broad-leaved cattail plants 6 weeks following second herbicidal application

Herbicidal application	Rate per acre*	Carbohydrate in oven-dry roots	Survival
	Pounds	Percent	Percent
2,4-D, isopropyl ester	108.0	26.7	0
isopropyl ester	84.1	31.4	0
isopropyl ester	55.7	25.9	5
isopropyl ester	46.8	33.5	0
isopropyl ester	41.5	22.5	0
isopropyl ester	27.3	26.6	0
sodium salt	**17.5	59.2	60
sodium salt	**13.1	56.5	40
isopropyl ester	12.0	20.9	0
isopropyl ester	9.2	21.6	15
isopropyl ester	7.5	22.1	10
isopropyl ester	7.0	28.5	5
isopropyl ester	6.3	22.0	15
isopropyl ester	3.4	20.3	20
isopropyl ester	1.4	29.7	25
Maleic hydrazide	80.4	45.1	80
Pentachlorophenol	***571.9	55.0	10
Untreated controls	0.0	56.8	100
	0.0	40.2	100
	0.0	36.8	100

*Rate expressed as acid equivalent or active ingredient.
**Sodium salt of 2,4-D was applied with no wetting agent.
***Gallons per acre.

	Formulation of 2, 4-D	Total pounds per acre	Percent survival 6 weeks after second application
True water cress	Isopropyl ester	3.0	0
Water hyacinth	Isopropyl ester	18.2	5
Parrot's feather	Isopropyl ester	3.0	0
Ripgut grass (Water sedge)	Acid	16.4	15
Oregon sugar grass (Awned sedge)	Acid	34.0	5
Narrow-leaved cattail	Isopropyl ester	6 - 8	0
Broad-leaved cattail	Isopropyl ester	9 - 12	0

USE OF HERBICIDAL PELLETS IN THE CONTROL OF EMERGENT AQUATIC WEEDS

Procedure

Procedures and techniques for the emergent weed tests were similar to those previously described for the similarly treated submersed plants (page 29).

Results

Results of this work are reported in Table 21 and illustrated in Figure 24. Water cress, water hyacinth, and parrot's feather were killed with CMU concentrations between 16 and 19 ppm. However, dense waterweed was not affected by 50 ppm of CMU. A concentration of 20 ppm per acre foot of water is equal to an application of approximately 54 pounds per acre. The 2, 4-D free acid at 224 ppm cleared the tank of the initial vascular plant growth. Rosin amine D acetate at 13 ppm was effective in eliminating water cress but at 40 ppm 25 percent of the water cress made regrowth. Sodium borate at a concentration of 736 ppm eliminated 75 percent of the aboveground water cress growth. The regrowth was stunted.

Figure 24--Use of herbicidal pellets in the control of true water cress (*Nasturtium officinale*). Upper row of photographs shows initial condition of plant growth. Lower row of photographs shows tanks 5 weeks after herbicidal pellets were placed on the inundated soil bottom in which submersed rooted aquatic plants were growing. Treatments were as follows: A. Untreated, B. Alpha benzene hexachloride pellets, C. 2,4-D free acid pellets, D. Sodium borate crystals, E. 3-(p-chlorophenyl)-1, 1-dimethylurea (CMU) pellets. See Table 21 for herbicidal rates.

A

B

C

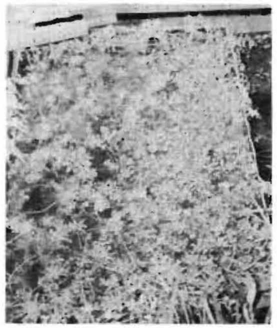
D

E

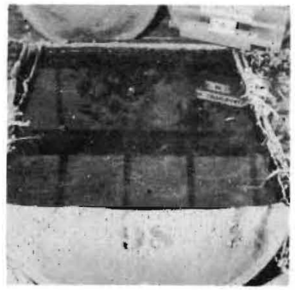
A

B

C



D



E

Table 21--Killing effect of selected herbicidal pellets on rooted emergent aquatic plant growth 10 months following contact with the plants

Chemical	Rate ppm	Treated plant	Comments
Sodium borate	736	Water cress	50% cover by horned pondweed 12.5% regrowth stunted 12.5% sago pondweed 12.5% broad-leaved cattail 12.5% Spirogyra
CMU (3-(p-chlorophenyl) -1, 1-dimethylurea)	15.8	Water cress	Tank clear of vegetation
	49.7	Dense waterweed	Survived--no effect
	18.7	Water hyacinth	Tank clear of vegetation
	17.0	Parrot's feather	Tank clear of vegetation
2, 4-D free acid	223.7	Water cress	Tank clear of vegetation
RADA (Rosin Amine D acetate)	39.9	Water cress	25% regrowth 75% replacement by Spirogyra
	12.8	Water cress	Tank clear of water cress 100% replacement by Spirogyra

Two goldfish survived 14.9 ppm of CMU from 5-12-53 to 6-16-53.
One goldfish survived 59.5 ppm of CMU from 6-16-53 to 6-18-53.
One goldfish survived 59.5 ppm of CMU from 6-16-53 to 6-23-53.

EFFECTS OF VARIOUS HERBICIDES OF LOW WATER SOLUBILITY ON BROAD-LEAVED CATTAIL UNDER FIELD CONDITIONS

Procedure

The five herbicides evaluated were: free acid of 2, 4-D, unground concentrated sodium borate, 3-(p-chlorophenyl) 1, 1-dimethylurea (CMU), sodium borate, and phenyldimethylurea (PDU). Pellets of 2, 4-D acid and PDU were made by mixing equal portions by weight of each herbicide with an equal weight of gum arabic and then compressing small amounts of the mixtures in a briqueting machine. The CMU was in the form of 10 percent CMU pellets. The unground concentrated borate was in the form of lumps and sodium borate was in a fine granular form. These herbicides were distributed evenly on the cattail plots at a time when the plants had emerged from a minimum of 10 cm to a maximum of 100 cm above the water. The treatments are outlined and presented in Table 22.

Table 22--The effects of various herbicides of low water solubility used as pellets or in granular form on broad-leaved cattail. These plots were treated on May 7, 1953. Samples were taken for root reserve analyses on June 8, 1953, and visual observations were continued through August 21, 1953.

Plot	Formulation and rate	Percent carbohydrate root reserve	Estimated percent regrowth
1	50-50 mixture of the free acid of 2, 4-D and gum arabic made into pellets. 20 lb of 2, 4-D acid per acre	23.4	100
2	Unground concentrated sodium borate 100 lb per acre	24.2	100
3	10 percent 3-(p-chlorophenyl)1, 1-dimethylurea (CMU) pellets 20 lb of CMU per acre	27.4	100
4	Sodium borate 100 lb per acre	24.6	100
5	50-50 mixture of phenyldimethylurea (PDU) and gum arabic made into pellets. 20 lb of PDU per acre	19.5	100
Untreated control	--	27.6	

Results

The carbohydrate root reserve was reduced considerably in the plot treated with PDU. Approximately 1 month after treatment, all the plots except No. 3 appeared to be growing normally. In Plot No. 3, which was treated with CMU at the rate of 20 pounds per acre, there appeared to be a definite suppression of growth to 40 to 60 percent of the plants in the plot. As the growing season progressed, there seemed to be less suppression of growth.

MOVEMENT OF 2, 4-D OR ITS EFFECTS PAST THE WATER LINE IN AQUATIC PLANTS

It was desirable to know whether 2, 4-D would move past the water line when emergent aquatic plants were treated with this herbicidal compound. The qualitative procedure developed by Freed (26) was utilized in this investigation to determine if 2, 4-D could be detected in the under water roots of top-treated cattail plants, the leaves of which had been sprayed with this phenoxyacetic acid derivative.

Procedure

Fifteen selected pulverized cattail root specimens from plants that had received an aerial application of 2, 4-D were extracted with benzene in a Soxhlet extraction apparatus. The benzene extract was evaporated to dryness in a test tube, a few crystals of chromotropic acid (1, 8-dihydroxy naphthalene 3, 6-disulfonic acid) introduced, 2 ml of concentrated sulfuric acid added, and the material heated in a glycerine bath at 150° C for 1-1/2 to 2 minutes. In this procedure the rapid development of a deep wine-purple color is indicative of the presence of 2, 4-D.

Results

In this test, 9 out of 14 of the cattail roots examined appeared to give the color reaction which indicated presence of 2, 4-D. In work previously reported (36, 63), autoradiographs of emergent and submersed aquatic vascular plants, both of which had been treated with radioactive 2, 4-dichlorophenoxyacetic acid (2, 4-D-1-C^{14}), indicated that the water line does not act as a barrier for passage of 2, 4-D through the respective aquatic plant systems.

AN AQUATIC WEED USEFUL AS A 2, 4-D VAPOR INDICATOR PLANT

Due to the extreme sensitivity of parrot's feather to the isopropyl ester vapors of 2, 4-D, this plant would appear to have important potential useage as a 2, 4-D vapor-indicator plant in environs where 2, 4-D applications are being made. These excised plants placed in ordinary household Mason fruit jars filled with tap water could be easily and readily distributed in fields containing 2, 4-D sensitive crops such as cotton, grapes, tomatoes, etc., before application of this systemic herbicide to adjacent weed infested areas. Greenhouse observations indicate that vapors drifting into crop fields will affect the parrot's feather with lower concentrations of 2, 4-D than they will any of the above-mentioned crop plants. Typical effects of 2, 4-D vapors on parrot's feather are shown in Figure 25.

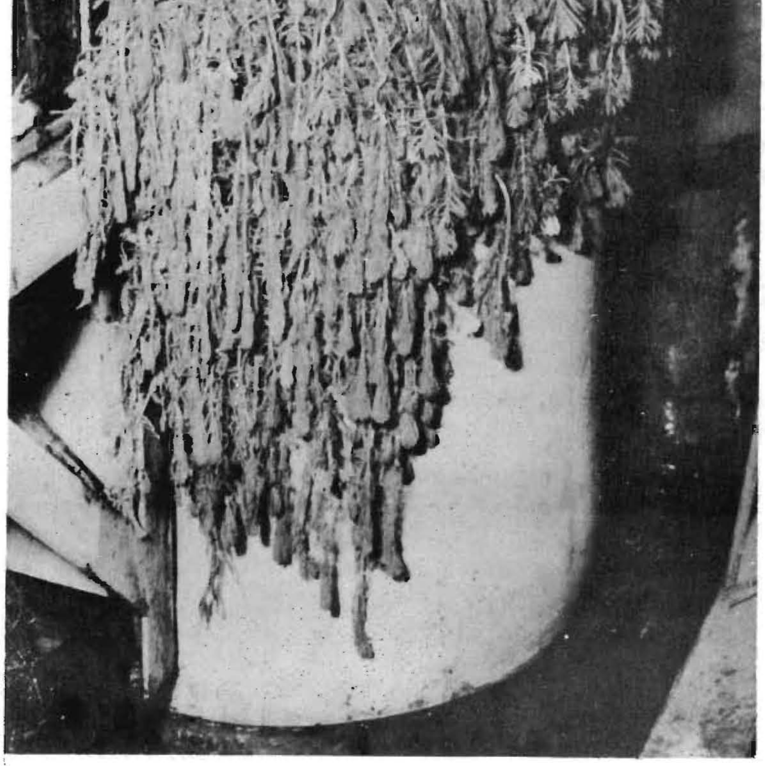


Fig. 25 Extreme sensitivity of parrot's feather to the isopropyl ester vapors of 2, 4-D suggest its use as a 2, 4-D vapor-indicator plant in environs where 2, 4-D applications are being made.

CATTAIL ROOT RESERVE STUDIES

Seasonal Carbohydrate Reserve Trends in Roots and Rhizomes of Broad- and Narrow-leaved Cattails

It seemed desirable to study the changes in root reserves in cattail underground plant parts which were due to seasonal growth phenomena. Having established the period, or periods, of low root reserve, it would then be possible to determine whether making herbicidal applications (contact or systemic) when root reserves are at a low ebb would give maximum killing effect.

Procedure

In order to determine the comparative normal amount of organic food reserves of different kinds in roots of broad- and narrow-leaved cattails, root samples of both species were taken from water-inundated growing sites on April 10, 1950. Protein, crude fat, and carbohydrate determinations were performed on the root samples in accordance with methods suggested by Lepper (41), Loomis and Shull (43), and Woodman (92).

In the major phase of this study, measurements of broad- and narrow-leaved cattail roots and rhizomes were made throughout the entire growing season in an attempt to correlate below ground carbohydrate root reserves with easily observed aboveground phenomena. Carbohydrate root reserves were determined on the samples taken at weekly intervals, and associated aboveground phenomena were recorded for the following situations:

1. Growing site inundated by water
    - a. Fruiting broad-leaved cattail
    - b. Nonfruiting broad-leaved cattail
    - c. Mixture of fruiting and nonfruiting narrow-leaved cattail
2. Growing site not inundated by water (subirrigated)
    - a. Mixture of fruiting and nonfruiting broad-leaved cattail
    - b. Nonfruiting narrow-leaved cattail

Weekly notes on the aboveground phenomena for cattails in the above five categories were recorded as follows: (a) date of collection, (b) appearance of fruiting bodies, pollination time, etc., (c) water temperature approximately 8 inches below lake surface, (d) height of plants above water surface or ground line, (e) total length of plant shoots, (f) width of leaf, (g) total length of seed stalk, (h) length of the female and male spikes, (i) width of female spike.

Weekly laboratory data were recorded as follows: (a) shoot and root fresh weight, (b) shoot and root oven-dry weight, (c) percentage dry matter in shoots and roots, and (d) percentage readily hydrolizable carbohydrate in oven-dry roots.

After field linear measurements had been made on about seven specimens from each grouping as listed earlier, the cattails were dug, brought into the laboratory, the soil washed off the roots, and the laboratory linear measurements made. The roots were then separated from the shoots (line of separation determined by the point of emergence of fibrous roots) and cut up into approximately 1/2-inch lengths. The shoots and roots were placed in separate paper sacks and weighed. The samples were then placed in separate 6-inch cubical wire baskets and heated in a drying oven at 100° C for 30 minutes as suggested by Miller (51) to inactivate the enzymes present. The oven temperature was then lowered to 62° C and the plant material heated for 72 hours. The oven-dried shoots and roots were transferred to separate paper sacks and reweighed. The shoots were then discarded and the roots were stored in paper sacks in a cool, dry place so that later chemical analyses could be made on the specimens collected at weekly intervals through the growing season.

Carbohydrate root reserve in broad- and narrow-leaved cattail samples was determined as follows:

The dried, stored roots were pulverized in a Quaker City mill so that approximately 99.8 percent passed a No. 16 sieve. To insure a uniform sample being taken, all the ground sample passing the No. 16 sieve was thoroughly mixed with a spatula, after which a 3-gram sample was weighed on a torsion balance.

Carbohydrate analyses were performed in accordance with methods suggested by Schaffer and Hartmann (72) and Lange (40). It was recognized that, in cattail roots, starch is accompanied by root reserves such as pentosans and various hemicelluloses that also yield reducing sugars upon hydrolysis. The method of direct acid hydrolysis was relatively quick and easy to execute and sufficiently accurate to give results comparable with published analyses.

Results

Results from the crude fat, protein, and carbohydrate analyses are shown in Table 23. The majority of root reserves in broad- and narrow-leaved cattail were found to be in the form of carbohydrates. Relatively small quantities of crude fat and protein were present.

Table 23--Food reserve content of roots of untreated cattail plants collected April 10, 1950, from growing site inundated by water

Name of plant	Percentage crude fat[1]	Percentage protein[2]	Percentage carbohydrate[3]
Narrow-leaved cattail *Typha angustifolia* L.	0.528	2.55	60.2
Broad-leaved cattail *Typha latifolia* L.	1.293	6.73	54.4

[1]Lepper (41) Woodman (92)
[2]Lepper (41) Woodman (92)
[3]Loomis and Shull (43), Schaffer and Hartman (72), Woodman (92)

Data pertaining to seasonal carbohydrate root reserve trends in roots and rhizomes of broad- and narrow-leaved cattails are presented in Tables 24-28. From these tables, percentage readily hydrolyzable carbohydrate root reserve in oven-dry roots, percentage dry matter in fresh roots, and centimeters height of cattail growth above water or ground surface are graphically presented in Figures 26-30. A discussion of these findings follows.

Trend of readily hydrolyzable carbohydrate in oven-dry roots. In early spring and fall and presumably during the winter dormancy period, cattail roots of both species had a carbohydrate root reserve of approximately 55-70 percent. With the beginning of shoot growth in the spring, reserves decreased gradully at first and then more rapidly as plant development progressed. In the three broad-leaved cattail growth situations, minimum root reserves of about 20 to 26 percent were reached on June 12 in the two inundated sites and on May 22 in the noninundated site. This minimum was followed in each situation by a rapid increase of food reserves for 6 to 8 weeks, after which the trend continued gradually upward to the end of the growing season.

In the two narrow-leaved cattail growth situations, a similar decrease in root reserves occurred as plant development progressed, followed by the gradual increase of reserve food which continued to the end of the growing season. However, the trend was much more irregular in this species. It was of interest to note that the minimum readily hydrolyzable carbohydrate root reserve obtained for the narrow-leaved cattail was about 43 percent, as compared to about 23 percent in the broad-leaved species. Field observations indicated that the narrow-leaved cattail roots were more heavily laden with starch than were the roots of their frequent field associates, broad-leaved cattail. The minimum reserve for narrow-leaved cattail was reached June 12 in the inundated site and July 3 in the noninundated site, in both cases coincident with the period of most rapid shoot growth.

Variation of carbohydrate root reserve in quintuplet samples of broad- and narrow-leaved cattails performed in accordance with the

Table 24--Carbohydrate root reserve study on mixture of fruiting and nonfruiting narrow-leaved cattail plants developing in the field from growing site inundated by water

Specimen number	Date	Lake surface water temperature °F	Height above water surface cm	Length cm Leaf	Length cm Seed stalk	Length cm Female spike	Width cm Female spike	Percentage dry matter Shoots	Percentage dry matter Roots	Percentage carbohydrate Oven-dry roots
1	3-20-50	45.8							21.1	58.5
2	3-27-50	51.8						12.5	26.1	63.3
3	4- 3-50	53.1						13.5	26.6	63.8
4	4-10-50	54.2	8.9	20.3				10.5	22.0	60.2
5	4-17-50	52.2	10.5	27.9				9.0	28.5	65.1
6	4-24-50	57.5	33.8	33.7				8.8	23.7	64.7
7[a]	5- 1-50	54.2	24.1	38.9				10.8	23.2	63.5
8	5- 8-50	52.5	47.3	63.1				8.9	22.4	66.0
9	5-15-50	66.0	68.9	76.3				10.4	22.4	66.9
10	5-22-50	76.5	106.7	93.8				13.5	24.7	59.0
11[b]	5-29-50	66.1	97.0	84.3				13.3	19.2	60.9
12[c]	6- 5-50	74.0	107.3	115.9				17.3	18.4	43.0
13	6-12-50	73.0	125.9	150.7	119.6	12.4	0.5	22.2	15.7	41.8
14[d]	6-19-50	75.0	107.6	130.2	128.0	10.9	0.6	15.5	17.7	59.3
15[e]	6-26-50	84.0	130.1	133.9	128.7	10.6	0.9	22.7	18.8	56.2
16[f]	7- 3-50	82.5	130.5	148.2	141.5	10.6	0.9	17.2	12.2	46.0
17	7-10-50	80.5	142.5	142.4	134.4	10.9	1.2	22.6	15.7	49.0
18	7-17-50	71.5	160.4	151.1	133.1	11.7	1.6	18.9	15.2	43.9
19	7-24-50	70.0	163.2	178.3	152.9	13.7	1.7	17.2	12.2	44.9
20	7-31-50	72.5	149.5	157.6	123.9	10.9	1.7	22.4	16.5	53.3
21	8- 7-50	78.5	163.3	168.4	152.0	13.3	1.8	27.1	17.3	57.0
22	8-14-50	79.5	172.3	188.6	152.7	12.7	1.7	27.6	17.9	58.2
23	8-21-50	66.3	177.3	205.8	162.5	14.4	1.8	24.9	15.9	58.8
24	8-28-50	53.0	180.7	197.9	164.1	16.5	1.8	27.8	20.6	63.3
25	9- 5-50	76.5	184.2	191.9	172.4	17.4	1.8	27.8	20.8	64.0
26	9-11-50	57.0	178.9	206.8	169.0	17.1	1.7	24.2	17.8	61.5
27[g]	9-18-50	61.6	162.8	184.2	167.6	15.6	1.8	27.1	20.0	59.9
28	9-25-50	60.5	166.2	217.8	176.4	17.3	1.8	25.4	20.5	67.2
29	10- 2-50	55.0	180.1	229.0	172.3	16.8	1.6	21.5	17.8	61.5
30	10- 9-50	54.0	172.5	186.9	159.2	15.4	1.6	25.6	24.2	64.1

[a] Cattail tops frozen back 6 to 8 inches.
[b] Green cattail leaves knocked down to water surface by snow.
[c] Fruiting bodies beginning to appear.
[d] Beginning pollination.
[e] Pollination 50 percent completed.
[f] Pollination completed. Female spike cinnamon brown.
[g] Considerable yellowing of cattails.

Table 25--Carbohydrate root reserve study on nonfruiting narrow-leaved cattail plants developing in the field from growing site not inundated by water

Specimen number	Date	Lake surface water temperature °F	Height above ground surface cm	Length: cm Leaf	Percentage dry matter Shoots	Percentage dry matter Roots	Percentage carbohydrate Oven-dry roots
1	3-20-50	45.8				26.5	62.3
2	3-27-50	51.8				26.2	57.4
3	4- 3-50	53.1				27.0	61.4
4	4-10-50	54.2				27.2	59.5
5	4-17-50	52.2				22.7	51.7
6	4-24-50	57.5		4.7		22.0	53.2
7[a]	5- 1-50	54.2				21.0	48.0
8	5- 8-50	52.5				16.5	44.4
9	5-15-50	66.0				19.8	49.5
10	5-22-50	76.5	23.9	23.3	14.8	23.4	57.8
11[b]	5-29-50	66.1	28.8	31.9	13.3	21.2	56.7
12	6- 5-50	74.0	35.0	42.8	15.9	22.7	51.8
13	6-12-50	73.0	54.4	56.1	13.8	21.2	53.4
14	6-19-50	75.0	67.9	72.6	13.7	17.1	49.9
15	6-26-50	84.0	87.9	86.3	21.1	23.0	58.0
16	7- 3-50	82.5	101.7	105.6	18.8	13.8	43.6
17	7-10-50	80.5	120.3	121.8	21.1	17.5	46.5
18	7-17-50	71.5	126.4	124.5	17.7	14.6	46.0
19	7-24-50	70.0	126.4	111.5	20.6	15.7	45.0
20	7-31-50	72.5	136.4	135.0	26.2	18.8	54.8
21	8- 7-50	78.5	141.5	140.4	29.0	19.4	55.8
22	8-14-50	79.5	142.7	142.9	26.1	16.4	49.2
23	8-21-50	66.3	136.3	140.9	30.7	22.0	55.0
24	8-28-50	53.0	148.5	146.7	30.8	22.8	61.5
25	9- 5-50	76.5	140.1	152.8	32.8	26.1	60.0
26	9-11-50	57.0	138.5	118.6	31.5	23.8	59.9
27[c]	9-18-50	61.6	138.3	150.7	42.1	28.7	63.0
28	9-25-50	60.5	137.3	111.1	33.1	29.4	61.1
29	10- 2-50	55.0	142.2	130.9	29.5	24.8	61.2
30	10- 9-50	54.0	123.4	116.1	45.0	24.7	62.2

[a]Cattail tops frozen back 6 to 8 inches.
[b]Green cattail leaves knocked down to water surface by snow.
[c]Considerable yellowing of cattails.

Table 26--Carbohydrate root reserve study on nonfruiting broad-leaved cattail plants developing in the field from growing site inundated by water

Specimen number	Date	Lake surface water temperature °F	Height above water surface cm	Length: cm Leaf	Percentage dry matter Shoots	Percentage dry matter Roots	Percentage carbohydrate Oven-dry roots
1	3-20-50	45.8	10.2	20.8	6.3	16.4	55.1
2	3-27-50	51.8	12.7	28.3	6.9	14.2	51.3
3	4- 3-50	53.1	14.0	29.7	8.3	15.2	52.8
4	4-10-50	54.2	27.3	28.2	7.9	16.3	54.4
5	4-17-50	52.2	24.8	62.7	8.6	13.5	50.8
6	4-24-50	57.5	49.4	69.5	7.0	15.1	39.8
7[a]	5- 1-50	54.2	53.4	82.7	8.4	14.4	48.5
8	5- 8-50	52.5	78.9	103.3	7.0	9.7	38.3
9	5-15-50	66.0	100.7	130.1	8.2	8.5	28.6
10	5-22-50	76.5	137.2	145.0	9.6	10.1	29.7
11[b]	5-29-50	66.1	129.2	147.3	9.8	7.9	25.2
12	6- 5-50	74.0	141.1	152.5	12.1	9.7	29.8
13	6-12-50	73.0	134.3	156.2	14.8	11.2	22.1
14	6-19-50	75.0	135.7	163.8	10.8	7.1	27.3
15	6-26-50	84.0	178.5	188.9	16.8	9.5	31.7
16	7- 3-50	82.5	180.7	209.5	15.0	8.2	32.1
17	7-10-50	80.5	177.0	185.3	20.1	9.5	33.7
18[c]	7-17-50	71.5	173.6	191.1	16.5	9.9	37.2
19	7-24-50	70.0	176.8	210.3	16.6	10.6	40.5
20	7-31-50	72.5	182.9	180.8	19.3	12.3	40.8
21	8- 7-50	78.5	186.4	213.1	25.3	13.0	49.4
22	8-14-50	79.5	190.6	221.7	20.9	15.7	59.9
23	8-21-50	66.3	208.6	240.9	23.2	17.9	62.7
24	8-28-50	53.0	192.8	229.0	22.4	17.8	63.2
25	9- 5-50	76.5	207.4	219.1	25.7	20.1	65.0
26	9-11-50	57.0	199.6	247.2	23.6	21.5	65.9
27[d]	9-18-50	61.6	195.8	243.5	25.0	25.1	69.5
28	9-25-50	60.5	196.5	232.6	27.5	24.1	68.7
29	10- 2-50	55.0	169.4	235.0	22.9	23.9	69.8
30	10- 9-50	54.0	158.0	208.4	28.0	25.3	72.0

[a]Cattail tops frozen back 6 to 8 inches.
[b]Green cattail leaves knocked down to water surface by snow.
[c]Broad-leaved cattail vegetative tips browned.
[d]Considerable yellowing of cattails.

Table 27--Carbohydrate root reserve study on fruiting broad-leaved cattail plants developing in the field from growing site inundated by water

Specimen number	Date	Lake surface water temperature °F	Height above water surface cm	Length cm: Leaf	Length cm: Seed stalk	Length cm: Female spike	Width cm: Female spike	Percentage dry matter: Shoots	Percentage dry matter: Roots	Percentage carbohydrate: Oven-dry roots
1	3-20-50	45.8	10.2	21.1				6.5	16.7	57.0
2	3-27-50	51.8	12.7	32.2				6.9	15.0	51.7
3	4- 3-50	53.1	14.0	19.3				9.8	15.2	52.1
4	4-10-50	54.2	27.3	39.1				7.2	15.4	48.4
5	4-17-50	52.2	32.7	35.9				7.5	14.0	50.7
6	4-24-50	57.5	56.9	80.7				7.6	13.1	46.6
7[a]	5- 1-50	54.2	58.0	74.2				6.9	15.2	46.5
8	5- 8-50	52.5	91.0	113.0				7.1	10.5	40.9
9	5-15-50	66.0	106.0	120.5				7.8	10.7	40.4
10	5-22-50	76.5	137.2	141.6				10.5	10.0	32.4
11[b]	5-29-50	66.1	122.3	158.9				9.9	8.3	24.8
12[c]	6- 5-50	74.0	130.7	174.1				11.3	8.8	25.1
13	6-12-50	73.0	145.9	161.7	131.6	14.7	0.9	16.0	9.9	20.5
14[d]	6-19-50	75.0	141.1	160.1	144.2	9.4	1.0	10.8	7.5	21.3
15[e]	6-26-50	84.0	138.4	176.7	164.4	17.1	1.6	16.3	9.5	27.0
16[f]	7- 3-50	82.5	140.8	166.5	154.9	14.4	2.0	13.8	7.7	24.9
17	7-10-50	80.5	155.1	179.2	175.2	11.5	1.8	18.8	9.8	30.4
18[g]	7-17-50	71.5	165.9	186.5	178.1	13.8	2.2	31.0	9.2	33.5
19	7-24-50	70.0	148.7	158.6	153.1	12.7	2.6	20.6	11.6	34.0
20	7-31-50	72.5	154.0	173.1	170.1	12.5	2.8	23.0	12.0	30.6
21	8- 7-50	78.5	169.4	191.8	185.4	14.0	2.8	27.9	11.9	33.5
22	8-14-50	79.5	166.4	198.8	189.7	13.5	2.6	21.4	9.6	32.2
23	8-21-50	66.3	170.8	197.9	188.3	12.7	2.7	26.1	14.4	46.1
24	8-28-50	53.0	167.9	193.7	182.5	12.5	2.7	26.0	13.4	49.3
25	9- 5-50	76.5	174.4	205.9	186.6	13.7	2.8	25.0	17.1	54.5
26	9-11-50	57.0	159.6	213.4	196.8	14.6	2.8	25.5	13.0	44.1
27[h]	9-18-50	61.6	155.7	201.6	194.2	13.9	2.8	27.4	17.3	52.6
28	9-25-50	60.5	164.4	210.2	202.7	14.2	2.7	31.2	16.2	54.6
29	10- 2-50	55.0	166.9	207.2	198.6	14.3	2.7	31.8	20.3	61.0
30	10- 9-50	54.0	155.2	201.6	196.1	14.1	2.6	33.7	17.2	56.4

[a]Cattail tops frozen back 6 to 8 inches.
[b]Green cattail leaves knocked down to water surface by snow.
[c]Fruiting bodies beginning to appear.
[d]Pollinating heavily.
[e]Pollination 90 percent completed.
[f]Pollination completed. Female spike black-brown.
[g]Vegetative tips browned.
[h]Considerable yellowing of cattails.

Table 28--Carbohydrate root reserve study on mixture of fruiting and nonfruiting broad-leaved cattail plants developing in the field from growing site not inundated by water

Specimen number	Date	Lake water water temperature °F	Height above ground surface cm	Length cm: Leaf	Length cm: Seed stalk	Length cm: Female spike	Width cm: Female spike	Percentage dry matter: Shoots	Percentage dry matter: Roots	Percentage carbohydrate Oven-dry roots
1	3-20-50	45.8							26.1	55.2
2	3-27-50	51.8							23.5	54.0
3	4- 3-50	53.1							29.2	47.4
4	4-10-50	54.2	3.3						27.8	58.1
5	4-17-50	52.2	17.7					9.9	26.7	43.8
6	4-24-50	57.5	14.7	15.1				10.9	20.0	43.3
7[a]	5- 1-50	54.2	24.9	25.7				8.6	20.7	49.3
8	5- 8-50	52.5	42.9	51.4				7.2	12.2	37.9
9	5-15-50	66.0	54.8	46.6				7.9	13.4	41.8
10	5-22-50	76.5	59.4	84.7				12.0	13.4	25.9
11[b]	5-29-50	66.1	67.9	86.0				11.1	12.2	27.2
12[c]	6- 5-50	74.0	67.0	69.2				16.0	21.4	36.9
13	6-12-50	73.0	84.8	108.7				22.3	20.4	45.9
14[d]	6-19-50	75.0	115.3	125.2				14.4	12.0	34.6
15[e]	6-26-50	84.0	115.6	97.8				19.9	17.0	40.6
16[f]	7- 3-50	82.5	119.0	130.1				17.6	13.4	38.8
17	7-10-50	80.5	147.8	143.4		14.1	1.4	22.3	14.1	47.1
18[g]	7-17-50	71.5	139.9	133.2	146.5			20.1	17.0	48.0
19	7-24-50	70.0	134.1	141.2	146.6	11.5	2.2	23.6	18.4	46.8
20	7-31-50	72.5	170.1	165.2	153.9	11.9	2.8	24.6	19.9	49.7
21	8- 7-50	78.5	157.7	150.8	151.7	12.0	2.7	26.7	20.9	50.5
22	8-14-50	79.5	167.2	148.8	149.6	11.9	2.9	26.9	23.3	60.2
23	8-21-50	66.3	154.5	162.5	156.5	11.3	2.8	25.9	22.9	59.3
24	8-29-50	53.0	162.3	163.1	156.0	12.2	3.0	29.7	27.1	61.6
25	9- 5-50	76.5	153.2	156.6	142.3	14.8	2.9	34.2	28.1	59.2
26	9-11-50	57.0	162.6	150.4	139.6	11.1	2.8	30.4	28.7	60.9
27[h]	9-18-50	61.6	141.8	141.8	150.8	10.7	2.9	33.9	30.6	62.3
28	9-25-50	60.5	143.3	136.6	155.7	11.7	3.0	32.3	27.4	64.3
29	10- 2-50	55.0	154.9	138.2	135.8	13.1	2.9	34.0	24.9	57.7
30	10- 9-50	54.0	145.8	122.6	145.9	11.8	2.7	41.2	29.0	59.5

[a] Cattail tops frozen back 6 to 8 inches.
[b] Green cattail leaves knocked down to water surface by snow.
[c] Fruiting bodies beginning to appear.
[d] Pollinating heavily.
[e] Pollination 90 percent completed.
[f] Pollination completed. Female spike black-brown.
[g] Vegetative tips browned.
[h] Considerable yellowing of cattails.

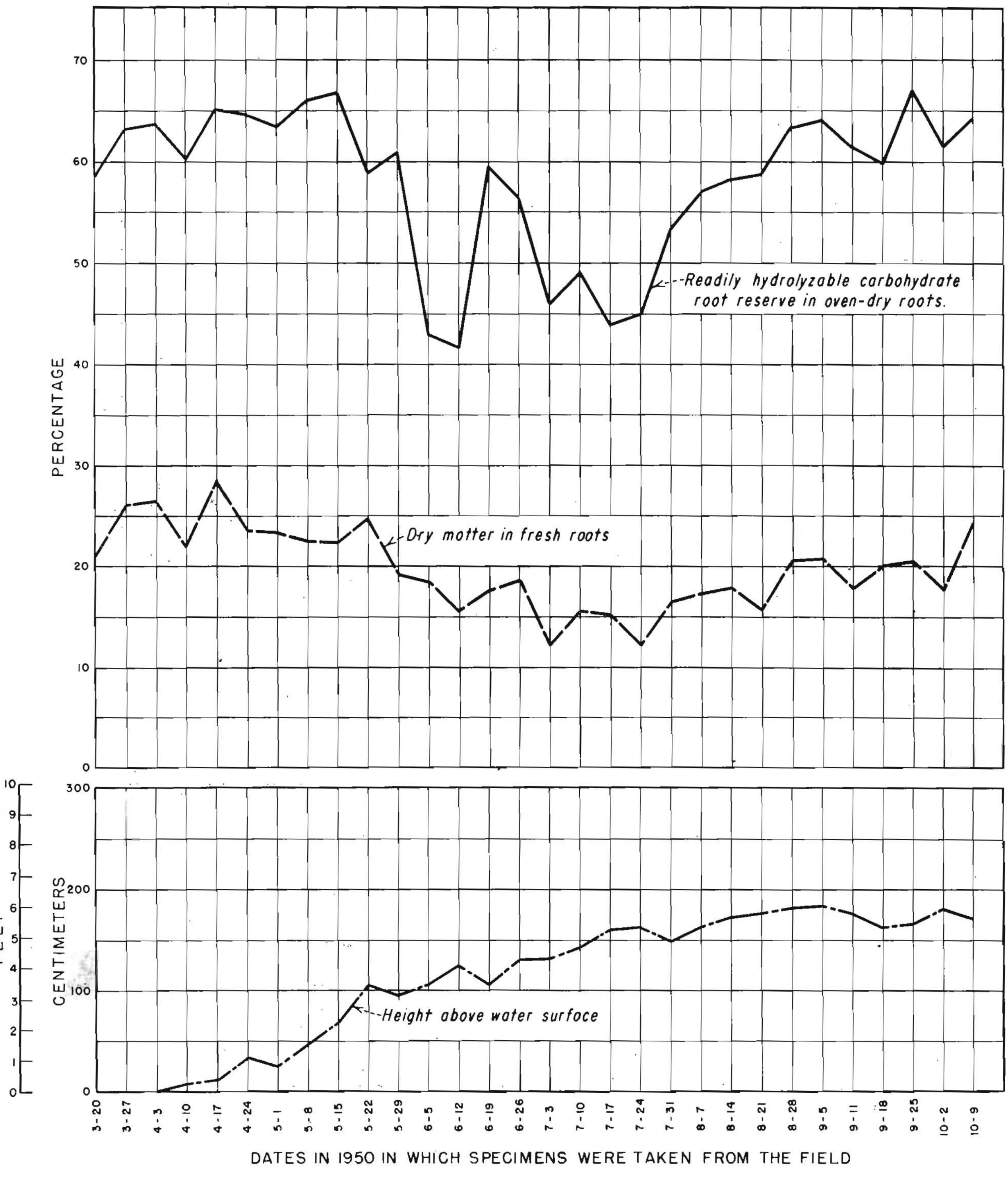


FIG. 26 - FIELD CARBOHYDRATE ROOT RESERVE STUDY ON MIXTURE OF FRUITING AND NONFRUITING NARROW-LEAVED CATTAIL PLANTS DEVELOPING FROM GROWING SITE INUNDATED BY WATER

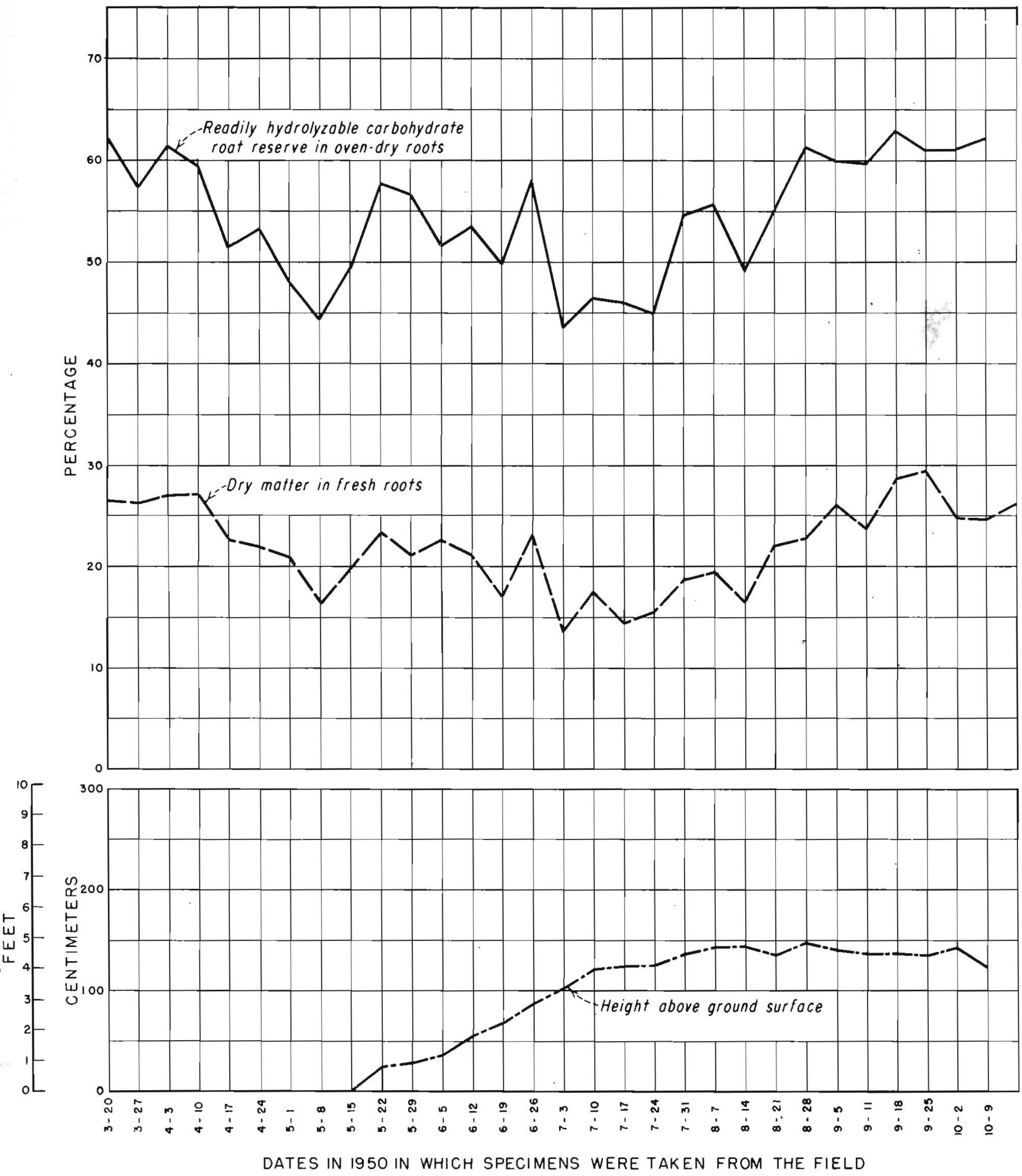


FIG. 27 - FIELD CARBOHYDRATE ROOT RESERVE STUDY ON NONFRUITING NARROW-LEAVED CATTAIL PLANTS DEVELOPING FROM GROWING SITE NOT INUNDATED BY WATER

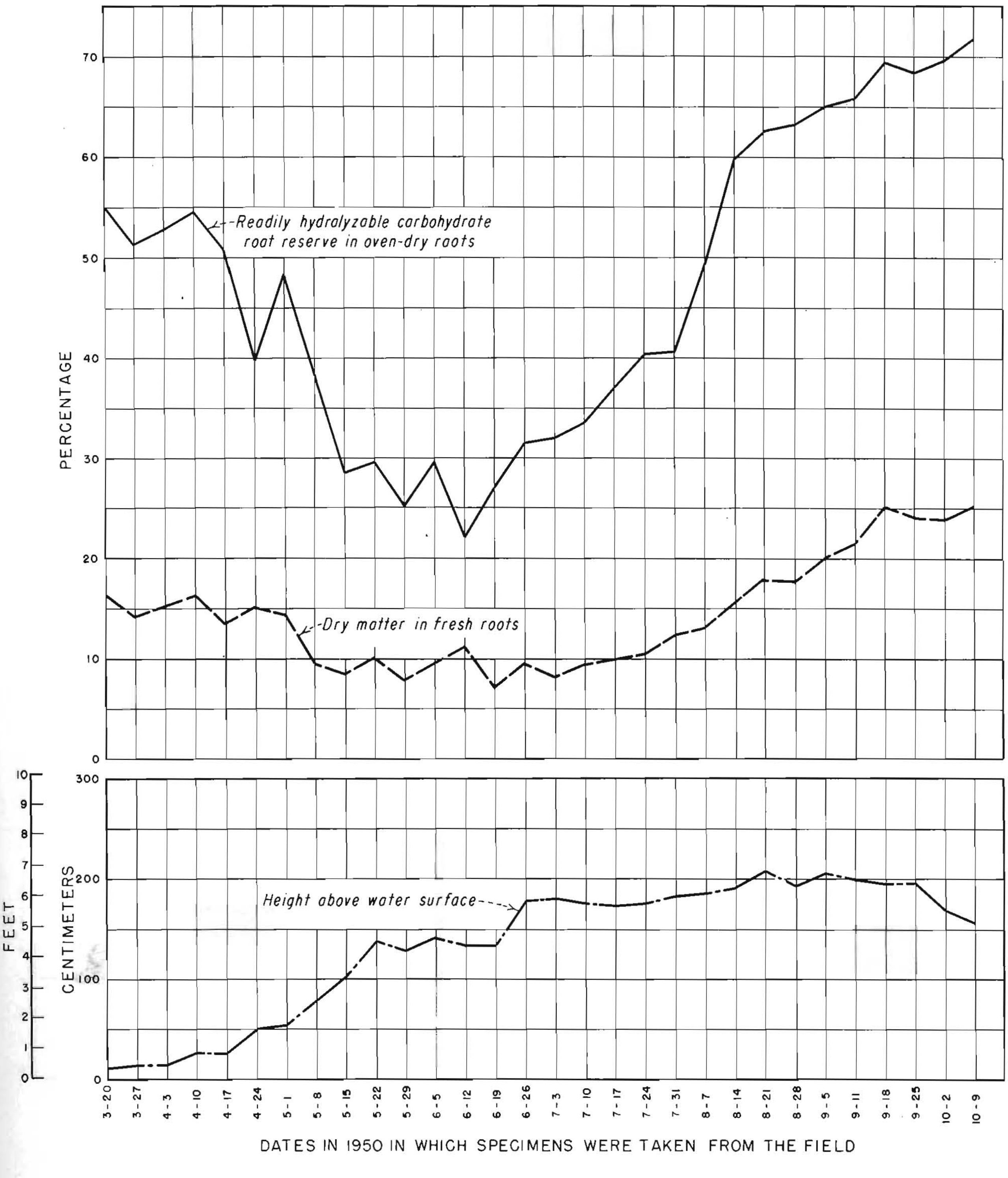


FIG. 28 - FIELD CARBOHYDRATE ROOT RESERVE STUDY ON NONFRUITING BROAD-LEAVED CATTAIL PLANTS DEVELOPING FROM GROWING SITE INUNDATED BY WATER

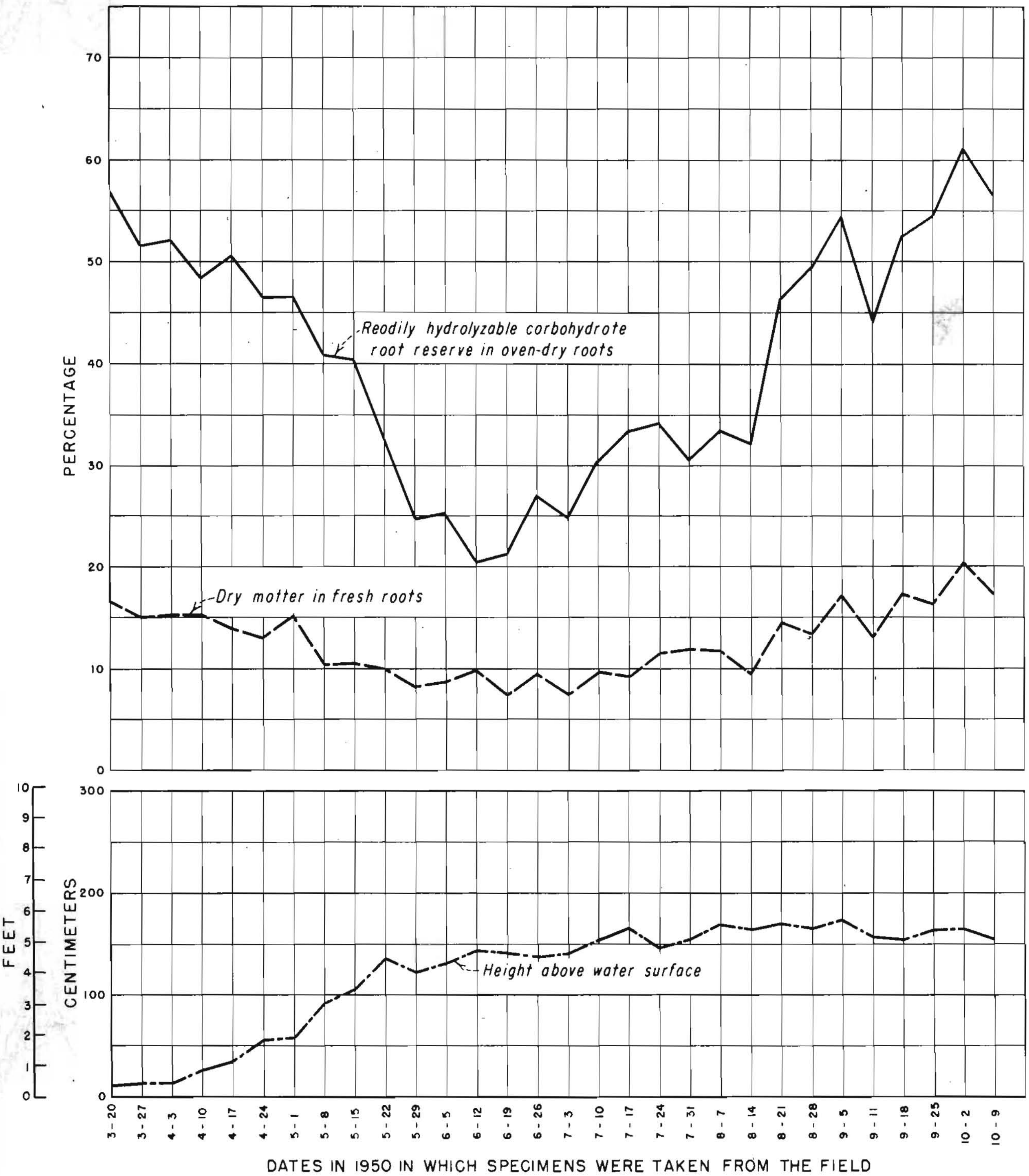


FIG. 29 - FIELD CARBOHYDRATE ROOT RESERVE STUDY ON FRUITING BROAD-LEAVED CATTAIL PLANTS DEVELOPING FROM GROWING SITE INUNDATED BY WATER

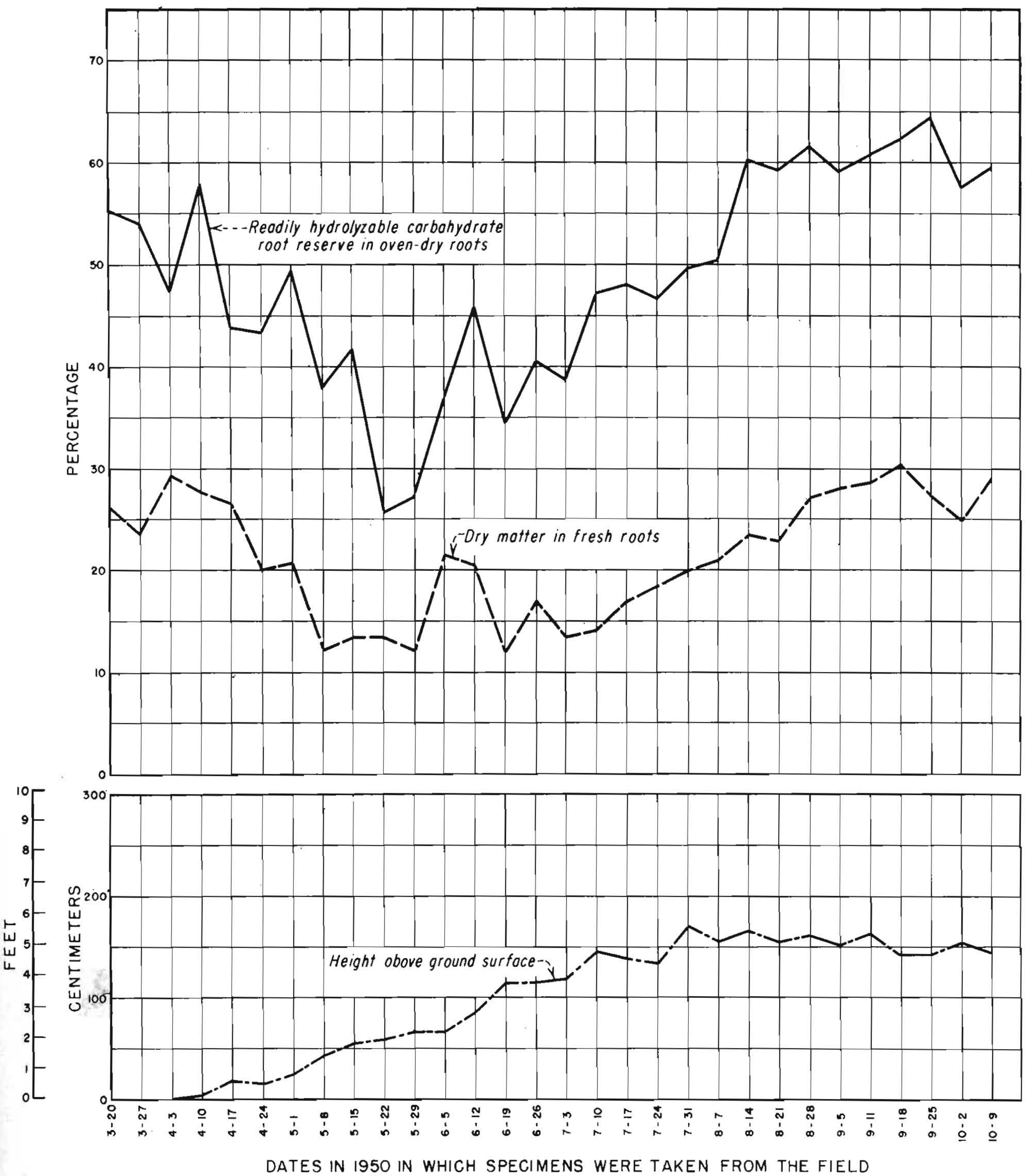


FIG. 30 - FIELD CARBOHYDRATE ROOT RESERVE STUDY ON MIXTURE OF FRUITING AND NONFRUITING BROAD-LEAVED CATTAIL PLANTS DEVELOPING FROM GROWING SITE NOT INUNDATED BY WATER

methods suggested by Schaffer and Hartmann (72) are presented in Table 29. It will be noted that with one exception the individual analyses were within plus or minus 0.5 percent of the respective arithmetical averages.

Table 29--Variation of carbohydrate root reserve in quintuplet samples of broad- and narrow-leaved cattails

Species	Specimen No.	Percentage carbohydrate in oven-dry roots	
Narrow-leaved cattail	1		45.07
Typha angustifolia L.	2		44.83
	3		44.83
	4		44.73
	5		45.23
		Average	44.94
Broad-leaved cattail	1		54.37
Typha latifolia L.	2		53.77
	3		53.30
	4		53.43
	5		53.77
		Average	53.72

Percentage dry matter in shoots and roots. In all of the five cattail growth situations investigated, there was a close agreement between the trend of percentage dry matter in fresh roots and that of percentage carbohydrate in oven-dry roots. With few exceptions, the direction of the two trends was the same for each date. The percentage of dry matter varied less from one date of sampling to another, showing a flatter curve than carbohydrates, as would be expected if carbohydrates are the only constituents in dry matter that are significantly affected by growth or respiration.

In the five cattail situations investigated, the percentage dry matter in the shoots began increasing rapidly 1 to 2 months after growth began and while carbohydrate reserves were still being depleted in the roots. Percentage dry matter in cattail roots continued to decrease 1 to 2 months after it began to increase rapidly in the shoots. On the fruiting and nonfruiting broad-leaved cattail plants developing in growing sites inundated by water, the percentage dry matter in the roots ranged between maximums of 20 to 25 and minimums of 7 to 8. For broad-leaved cattail plants developing in sites not inundated by water and for the narrow-leaved cattail plants developing in both the water-inundated and noninundated sites, the percentage dry matter in the roots ranged between maximums of about 28 to 30 and minimums of 12 to 14.

From the close agreement between the trends of total hydrolyzable carbohydrates and of dry matter, it can be seen that by making laboratory fresh and oven-dry weights on cattail root samples and calculating percentage dry matter in the same, it would be possible to follow the percentage carbohydrate in roots through the growing season without performing the more time-consuming, but more precise, chemical analyses.

Correlation between top growth of cattails and trend of carbohydrate root reserves. Comparable data are shown in Tables 24-28. Cattail growth in the water-inundated growing sites began March 20, 1950, when the water temperature was 45.8° F. In the sites not inundated by water, growth development came later, when water temperatures were much higher. This growth lag appeared to be associated with lower soil temperatures. The narrow-leaved cattail site not inundated by water was approximately 8 weeks behind the water-inundated one in beginning growth. After each snow and rain storm there was a noticeable drop in lake water temperature. Nevertheless, weekly temperatures inceased steadily up to the latter part of June, when a temperature of 84.0° was recorded. Warm temperatures held relatively steady until the middle of August, when there was a noticeable gradual decline to the final recording of 54.0° on October 9, 1950.

Rate of growth of cattail shoots was closely correlated with the decreasing trend in carbohydrate root reserves early in the season. Rapid shoot growth was associated with a rapid decrease in root reserves in each species on all sites. In the narrow-leaved and broad-leaved cattail growth site not inundated by water, root reserves were at the low point when the height of broad-leaved cattail was approximately 140 cm and the height of narrow-leaved cattail was 160 cm.

Plants developed from the growing sites inundated by water were, at maturity, approximately 30-50 cm taller than their counterparts developing in noninundated growth sites. Nonfruiting broad-leaved plants developing in inundated growth sites were approximately 40 cm taller than fruiting plants developing in similar sites.

At maturity, leaf lengths were approximately 30 cm more for nonfruiting than for fruiting broad-leaved cattail plants. Leaves on plants developed from the growing sites inundated by water were approximately 50-70 cm longer than on similar plants developing in noninundated growth sites.

Both species of cattail developed fruiting bodies on the site inundated by water, and broad-leaved cattail developed flower spikes on part of the site not inundated. The broad-leaved cattail site not inundated by water had a drainage ditch passing through it which carried water to a depth of 6 inches immediately following the occasional heavy spring rains in the area. In no instance, however, did water remain in the drainage channel more than 24 hours after these occasional rains. No fruiting bodies developed in the narrow-leaved cattails from the growing site not inundated by water.

Female and male spike lengths did not increase noticeably from time of their initial field appearance until they had attained full maturity. At maturity, in the growing sites inundated by water, leaf length extended beyond the seed stalk approximately 10 cm in the broad-leaved cattails and 30-40 cm in the narrow-leaved cattails.

In the inundated site, the broad-leaved cattail female spike increased rapidly in diameter from an initial 0.9 cm to the maximum 2.7 cm over an approximate 7-week period. The narrow-leaved cattail female spike in the inundated site likewise increased rapidly from an initial 0.5 cm to the maximum 1.7 cm in diameter over an approximate 6-week period. In both species of cattails, a low point in carbohydrate root reserves had been reached at the beginning of or early in this period and reserves remained relatively low during the rapid expansion of the female spike.

In summary, water-inundated narrow-leaved cattail had its low point in root reserves when the plants had emerged to an average height of 5 feet 3 inches (160 cm) above the water line and when the female spike had nearly reached maximum size. For nonindated narrow-leaved cattail, the low point occurred when the plants had emerged 4 feet above the ground line. For water-inundated broad-leaved cattail, the low point occurred when the plants had emerged 4 feet 7 inches above the water line and the flower spike had first appeared on the fruiting plants. For non-inundated broad-leaved cattail, the low point in root reserves occurred when the plants had emerged 3 feet 2 inches above the ground line more than 6 weeks before the first appearance of flower spikes. Thus, the low point in seasonal carbohydrate root reserves varied not only with the species involved, but with the growth habitat as well.

Since cattails, like other perennial plant species, are believed to be more effectively controlled by chemical or mechanical treatments applied at a low point in root reserves, this study of the seasonal trend of carbohydrate reserves in cattail roots and of associated growth phenomena should have considerable practical value in field control operations.

Effect of Repeated Clipping of Cattail Shoots on Carbohydrate Root Reserves

Procedure

In order to determine how many new shoots would develop from buds formed on single broad-leaved cattail rootstocks, eighteen rhizomes with clipped stalks were measured for bud lengths and placed in 4,000 and 3,000 ml beakers on October 26, 1949. The first crop of new growth from the buds was measured and harvested December 30, 1949. From time to time the new buds and growth were recorded and harvested. The number of new plant entities emerging from each individual basally clipped cattail rootstock was thus determined. Lateral buds used in this study and some of the growth obtained therefrom are illustrated in Figure 31. When the rhizomes were finally exhausted, the rhizomes were ground and stored for a percentage carbohydrate determination. These data should thus show the amount of starch, pentosans, and hemicelluloses still present in cattail rhizomes at the time of complete growth exhaustion.

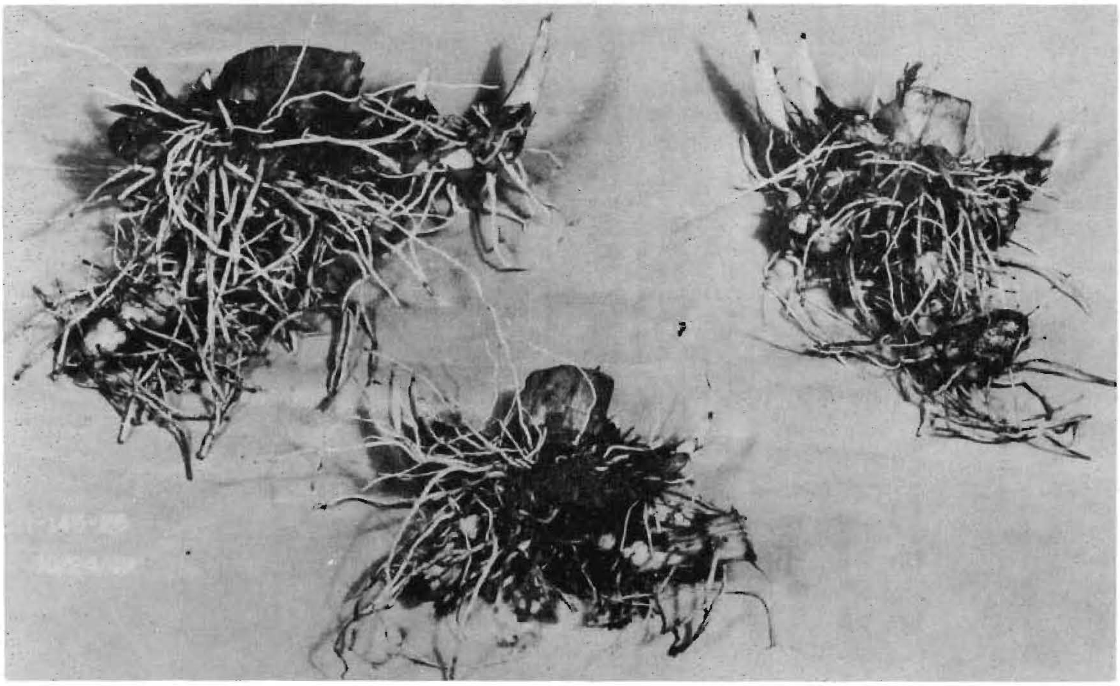
Results

Results from successive clippings of new regrowth developed from the initial basally clipped broad-leaved cattail rootstocks are presented in Table 30. These data show certain regrowth changes which take place upon gradual depletion of the carbohydrate root reserves in the initial rootstock. Between 2 and 26 new cattail buds, capable of independent growth, were found in this study to emerge over a period of several months from each of the initial basally clipped stocks used in the test. From 2 to 21 of these buds developed shoots, the number of shoots exceeding 14 in 5 of the rootstocks and 7 in 11 of the rootstocks. In several instances, even after a number of new plants had evolved from the old stock, an appreciable amount of root reserves remained to carry on new growth. In general, with successive clippings, there was (a) a decrease in the average shoot length, (b) a decrease in leaf width of the new plants developed, and (c) a decrease in the number of visible buds remaining. However, with several of the specimens these decreases did not become apparent until the fourth or fifth harvesting date. This study brought out the fact that lateral buds were formed anew at a rate almose commensurate with new growth. It can be expec- that a similar phenomenon occurs in the field. Apparently so long as lateral buds and adequate carbohydrate and other food reserves are retained in the underground parts, other conditions being favorable, clipped plants are capable of regenerating new plant growth.

Effect of 2, 4-D on Cattail Root Reserves in Greenhouse Cultures

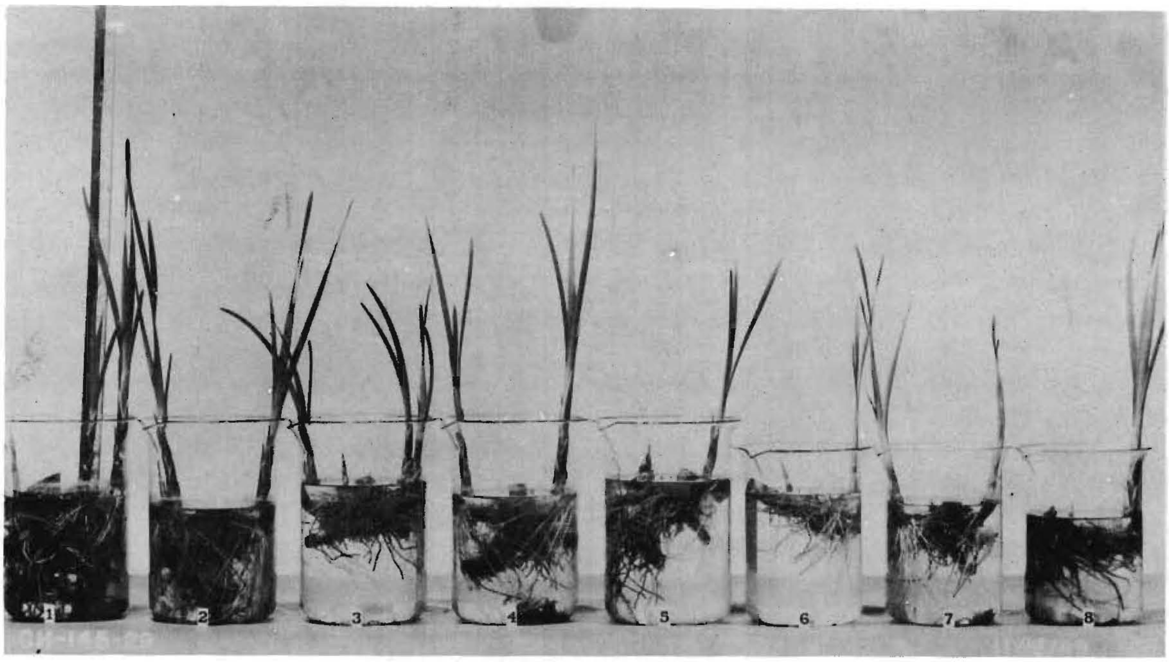
Procedure

Immediately preceding termination of winter dormancy, broad- and narrow-leaved cattail lateral buds were transplanted with soil intact



Broad-leaved cattail
Typha latifolia L.

Lateral or "winter" buds



Broad-leaved cattail
Typha latifolia L.

Fig. 31 New shoot regrowth from basely clipped root stocks

Table 30--Regrowth developed from basally clipped broad-leaved cattail rootstocks

Specimen number	Regrowth measurements on five successive sampling dates: (1) December 30, 1949; (2) July 25, 1950; (3) September 26, 1950; (4) October 18, 1950; and (5) August 27, 1951																					
	Number of shoots					Average shoot length, cm					Average leaf width, cm					Number of visible buds					Percent carbohydrate root reserve	
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	10-18-50	8-27-51
1	3	4	4	6	2	37.8	64.2	39.1	26.5	20.5	0.5	0.6	0.5	0.4	0.2	5	3	5	1	0		25.5
2	4	4	3	5	1	43.4	52.1	34.1	24.2	51.1		.5	.5	.4	.3	9	3	6	3	0		27.2
3	4	4	4	6	3	30.5	44.2	34.9	21.5	24.5		.6	.5	.4	.3	6	7	8	5	0		32.1
4	2	3	5	3	1	63.7	55.4	25.2	25.8	36.0		.4	.4	.4	.4	4	2	4	1	1		29.5
5	3	9	4	5	0	38.3	36.9	21.1	13.1		.9	.4	.4	.3		3	1	8	5	0	40.9	
6	2	2	4	3	0	31.8	40.6	13.6	10.4			.4	.3	.2		4	1	3	0	0	35.2	
7	2	3	1	1	0	41.6	38.7	52.7	18.7			.4	.6	.4		4	2	2	1	0	46.6	
8	1	4	1	1	0	55.9	44.7	25.0	10.2			.5	.5	.3		4	1	6	4	0	49.6	
9	3	1	2	2	0	33.2	19.2	27.3	6.3			.3	.3	.2		3	2	2	2	0	32.1	
10	1	2	2	2	0	55.2	30.3	21.4	14.4			.4	.5	.4		5	2	3	1	0	48.8	
11	1	2	0	0	0	9.5	51.8					.5				4	2	0	0	0		
12	3	0	0	0	0	25.8										2	0	0	0	0		
13	2	0	0	0	0	8.6										2	0	0	0	0		
14	2	3	2	2	0	7.7	22.0	6.4	3.7			.2	.2	.1		2	1	1	0	0		25.8
15	3	0	0	0	0	7.3										2	0	0	0	0		
Average	2.4	2.7	2.1	2.4	1.4	32.7	41.7	25.5	15.9	33.0	0.7	0.43	0.43	0.32	0.30	3.9	1.8	3.2	1.5	0.7	42.2	28.6

from the field into metallic containers of approximately 37-gallon capacity located in the greenhouse. The containers were then filled to capacity with tap water for the duration of the experiment. From work already discussed it was determined that, in general, cattails developing from growing sites inundated by water reach their relatively low period of root reserves when the plants attain a height of approximately 100-140 cm above the water surface. Accordingly, when the cattails had emerged above the water surface in the tanks to approximately this height, the emergent plants were sprayed in a manner to give complete coverage with the ester and amine salt of 2, 4-D at rates ranging from 1.4 to 108.1 pounds per acre. Rhizome sections were taken from specimens field dormant and 6 weeks following aerial herbicidal application on the greenhouse cattails. At the same time rhizome sections were taken from the untreated controls.

Part of the cut rhizome material from each treated and untreated tank and from the dormant field condition was killed, embedded, and sectioned in paraffin according to the methods described by Corrington (11) and Sass (71). Starch grains in the sectioned material were stained with iodine-potassium iodide.

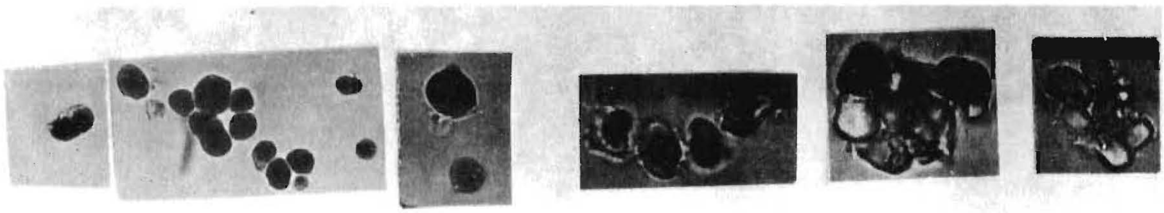
The remainder of the rhizome material collected and not used for histological section preparation was cut up into approximately 1/2-inch lengths, placed in separate 6-inch cubical wire baskets, and heated in a drying oven at 100° C for 30 minutes to inactivate the enzymes present (51). The oven temperature was then lowered to 62° C and the plant material heated for 72 hours. The dried rhizomes were pulverized in a Quaker City mill in such a manner that approximately 99.8 percent passed through a No. 16 (14-mesh) sieve. To insure a uniform sample being taken, all the ground sample passing the No. 16 sieve was thoroughly mixed with a spatula, after which a 3-gram sample was weighed on a torsion balance and chemical analyses proceeded according to the method suggested by Schaffer and Hartmann (72).

Results and Discussion

At the beginning of each growing season, many vascular plants use the starch food reserves stored in their roots to build new plant tissues. This process continues until such a time as the chlorophyll-bearing tissue of the new plant can manufacture food in the quantities needed for the new growth. As the plant growth slows up, the chlorophyll-bearing tissue in the new plant is able to catch up with, and then surpass, the immediate demands for food used in the manufacture of new tissue. This results in starch reserves being put back in the underground storage organs and made available for eventual future metabolic plant needs. Starch grains of four aquatic weeds are illustrated in Figure 32.

Figures 33 and 34 illustrate and present, in tabular form, the starch grain and carbohydrate findings on the treated cattail specimens. These are photomicrographs of the transverse-sectioned treated and untreated broad- and narrow-leaved cattail rhizome material. The average height of the two species of cattail above the flooded container water

A B

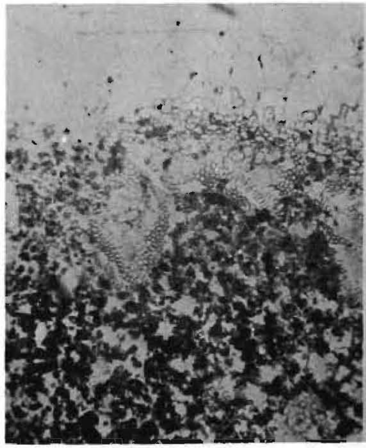


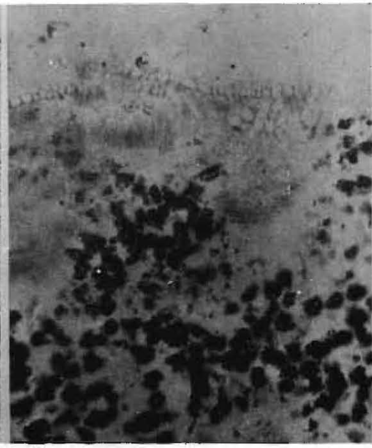
C D

Fig. 32 Starch grains of four aquatic weeds. A. Narrow-leaved cattail, *Typha angustifolia*, B. Broad-leaved cattail, *Typha latifolia*, C. American pondweed, *Potamogeton nodosus*, D. Sago pondweed, *Potamogeton pectinatus*. Magnification of all starch grains 400 X.

	A	B	C	D	E	F	G	H
Pounds per acre of 2,4-D	0.0	0.0	1.4	2.7	5.4	27.3	54.6	108.1
Height above water surface, cm	0.0	129.7	143.0	124.8	126.6	125.8	123.0	128.8
Percent carbohydrate root reserve	60.2	43.4	--	31.7	27.0	--	--	23.0
Starch grains	Abundant	Abundant	Present	Absent	Absent	Absent	Absent	Absent

Figure 33--Portions of transverse sections of narrow-leaved cattail (*Typha angustifolia*) rhizomes correlating rate of 2,4-D application, physical presence of starch grains in usual storage organs, and percentage carbohydrate in oven-dry roots. Magnification 120 X. To orient the rhizome portions illustrated, the endodermis is portrayed as a prominent single layer of cells approximately a quarter of the distance down from the top of each photomicrograph.

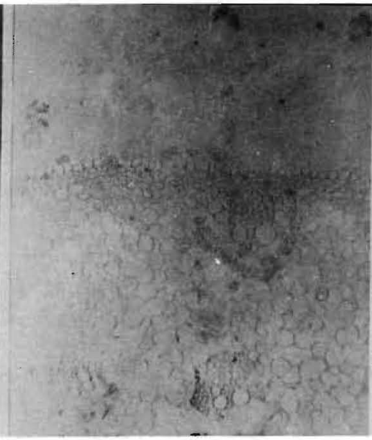

A


B


C


D


E

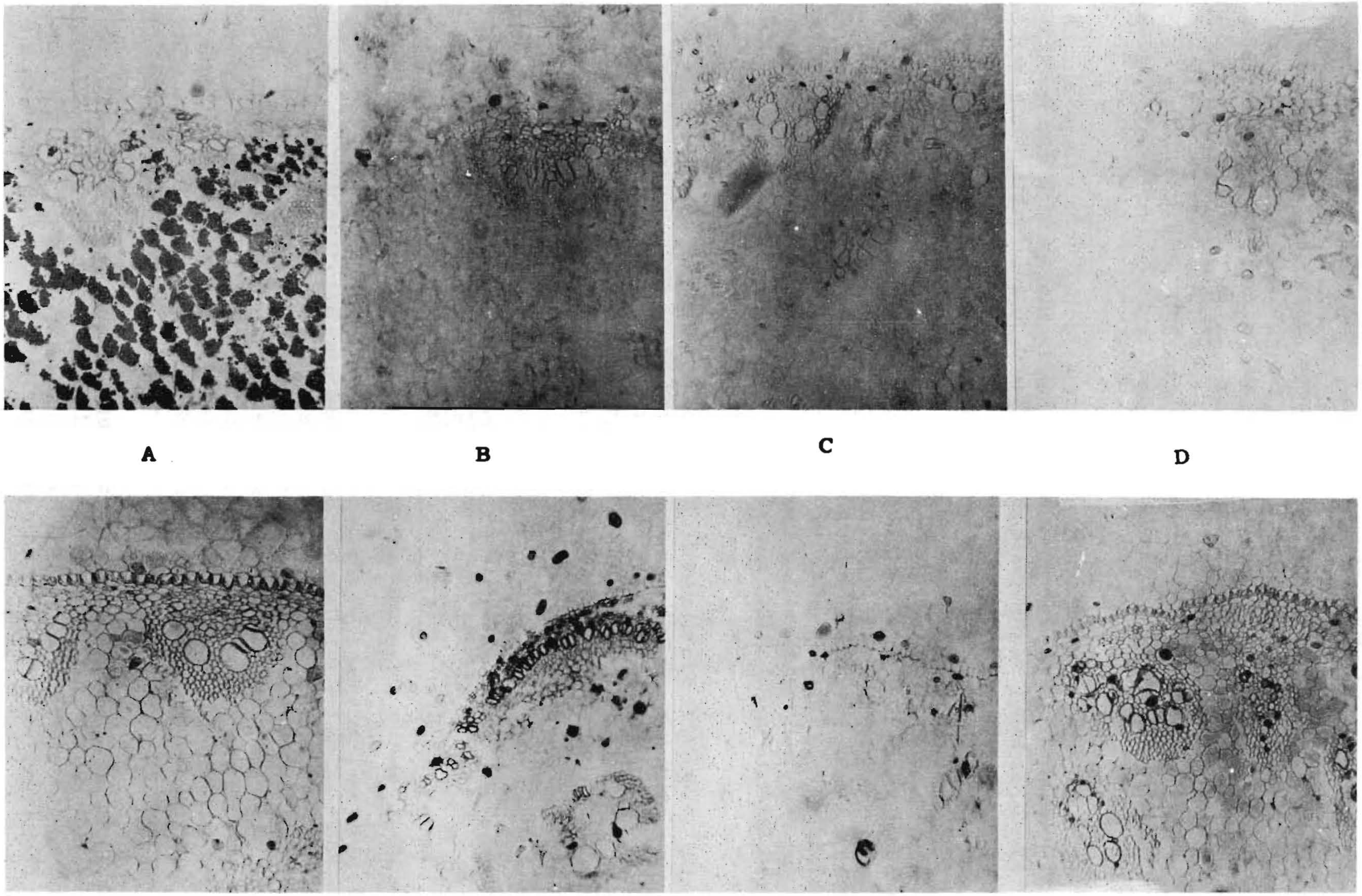

F


G


H

	A	B	C	D	E	F	G	H
Pounds per acre of 2,4-D	0.0	0.0	1.4	2.7	4.8	27.3	54.6	108.1
Height above water surface, cm	0.0	131.5	100.4	103.6	73.0	110.2	100.4	89.0
Percent carbohydrate root reserve	50.7	40.2	29.8	--	28.5	26.6	25.9	26.7
Starch grains	Abundant	Abundant	Present	Absent	Absent	Absent	Absent	Absent

Figure 34--Portions of transverse sections of broad-leaved cattail (Typha latifolia) rhizomes correlating rate of 2,4-D application, physical presence of starch grains in usual storage organs, and percentage carbohydrate in oven-dry roots. Magnification 120 X. To orient the rhizome portions illustrated, the endodermis is portrayed as a prominent single layer of cells approximately a quarter of the distance down from the top of each photomicrograph.



A B C D

E F G H

line varied from tank to tank, but it was believed that growth development was comparable and histological and carbohydrate analyses on the rhizomes present in the treated tanks could be directly attributed to physiological changes occurring as a result of the herbicidal application.

In interpreting the carbohydrate root analyses as determined by the method suggested by Schaffer and Hartmann (72) and Lange (40), it should be recognized that in cattail roots starch is accompanied by root reserves such as pentosans and various hemicelluloses that also yield reducing sugars upon hydrolysis. In this study it was found that in both species of cattails: (a) the starch grains were readily used up even when the lower concentrations of 2, 4-D were applied; (b) in general, the percentage carbohydrate decreased as the higher quantity of 2, 4-D per acre was applied, but decrease in carbohydrate was not in proportion to quantity of 2, 4-D applied; (c) application of excessive amounts of 2, 4-D did not deter carbohydrate utilization of food reserves in the cattail roots; (d) the amount of carbohydrate reduction in the roots from untreated dormant condition to plants receiving highest rates of 2, 4-D application was greater for the narrow-leaved cattail; and (e) while carbohydrate content was comparatively high in the roots of narrow-leaved cattail, reduction of the carbohydrate content was more readily affected with a given application of 2, 4-D, indicating this plant to be the more 2, 4-D susceptible of the two plants.

This study emphasizes the fact that relatively small quantities of 2, 4-D per acre, used at the correct time of plant development and with an adequate cosolvent or wetting agent present, are sufficient to have a pronounced effect on the reduction of starch grains and associated carbohydrates in cattail rhizomes upon which regrowth potential is dependent.

Effect of Aerial Herbicidal Treatment on Carbohydrate Root Reserves in Broad-leaved Cattail in Field Plots

Procedure

Herbicidal treatments were made on undisturbed broad-leaved cattail plants growing on the edges of a small lake in the environs of the Denver Federal Center. Treatment formulations, application date, and carbohydrate root reserve analyses on specimens harvested 5 and 6 weeks following treatment are outlined in Table 31. Application procedures and carbohydrate analyses were performed in a manner similar to that used on the materials transplanted to the metallic containers and described in the previous section.

In another test, the formulations used consisted of the isopropyl ester of 2, 4-D with and without VL-600 (see Table 32). Water was used as the carrier with all formulations and VL-600, when present, was added at the rate of 1 gallon to 30 gallons of water. The plots were sprayed at

Table 31--Effect of some different herbicidal formulations on carbohydrate root reserves in broad-leaved cattail

Plot number	Chemical, rate and volume of spray per acre	Percent carbohydrate root reserve 5 weeks after treatment
1	20 pounds of Endothal in 80 gallons of water	35.8
2	20 pounds of Endothal and 100 pounds of ammonium sulfate in 80 gallons of water	37.6
3	9.0 pounds of 2,4-D free acid, 48.0 pounds of trichloroacetate and 0.5 gallons of triethanolamine in 80 gallons of water	19.3
4	8.2 pounds of 2,4-D free acid, 0.5 gallons of triethanolamine in 80 gallons of water	26.6
5	30.0 gallons kerosene, 1.5 gallons tributyl phosphate	33.2
6	18.0 pounds 2,4-D free acid, 30.0 gallons kerosene, 1.5 gallons tributyl phosphate	20.6
Untreated control		37.7

Table 32--Herbicidal effect of the isopropyl ester of 2,4-D with and without VL-600 on broad-leaved cattail*

Plot	Formulation rate and volume per acre	Results 5 weeks after treatment	
		Percent carbohydrate root reserve	Estimated percent regrowth
A	Isopropyl ester of 2,4-D, 13.6 pounds acid equivalent in 80 gallons of water	27.1	2-5
B	Isopropyl ester of 2,4-D, 12.9 pounds acid equivalent and 2.7 gallons of VL-600 in 80 gallons of water	25.3	1-3
C	Isopropyl ester of 2,4-D, 8.7 pounds acid equivalent in 80 gallons of water	26.7	1-3
D	Isopropyl ester of 2,4-D, 7.9 pounds acid equivalent and 3.3 gallons of VL-600 in 100 gallons of water	24.7	2-5
E	Isopropyl ester of 2,4-D, 2.6 pounds acid equivalent and 2.2 gallons of VL-600 per acre in 80 gallons of water	23.8	100
G	Isopropyl ester of 2,4-D, 2.8 pounds acid equivalent in 80 gallons of water	25.2	75-90
Untreated control		38.3	

*Note that on Plot A some land plants such as the milkweed (Asclepias sp.) have grown up in front of the plots on the examined date.

rates varying from 80 to 110 gallons of solution per acre. The concentration of VL-600 was constant in all formulations where used. Concentration of the ester varied.

Results

Results of aerial herbicidal treatment on broad-leaved cattail plants treated in the field are presented in Tables 31 and 32 and illustrated in Figures 35 and 36, respectively. Endothal at 20 pounds per acre, both with and without ammonium sulfate added, was ineffective in reducing the carbohydrate in the treated specimens. However, the addition of ammonium sulfate to the Endothal prevented the formation of the normal female fruiting bodies. The cosolvent triethanolamine was only intermediately effective in bringing about a carbohydrate reduction from the 2, 4-D applied. The cosolvent, tributyl phosphate, and the carrier, kerosene, with no 2, 4-D addition were ineffective in reducing carbohydrates. Of considerable interest is the fact that presence of either trichloroacetate or tributyl phosphate was equally effective in bringing about carbohydrate reduction by the 2, 4-D present in the formulations (Plots 3 and 6). In both instances, carbohydrates were reduced to approximately 20 percent.

Applications of the isopropyl ester of 2, 4-D at the rates of 8.7 and 13.6 pounds per acre (acid equivalent basis) were effective in producing a near 100 percent top kill with a very small percentage of regrowth. This effect can be noted in Plots A and C (Table 32, Figure 36). The formulations were also effective in reducing the carbohydrates. Plots treated withthe formulations containing VL-600 and the isopropyl ester of 2, 4-D at the rates of 7.9 and 12.9 pounds per acre showed results similar to those in the plots mentioned above, as can be noted in Plots B and D. Plot E treated with a formulation containing VL-600 and the isopropyl ester of 2, 4-D at the rate of 2.6 pounds per acre and Plot G treated at the rate of 2.8 pounds per acre without VL-600 both showed a reduction in carbohydrates but very little effect on the regrowth. Apparently, the VL-600 added little, if any, effectiveness to the isopropyl ester of 2, 4-D.

Although the photographs in both Figures 35 and 36 were taken approximately 5 weeks after herbicidal application, percentage regrowth as evaluated over the remainder of the respective growing seasons was as discussed above and listed in Table 32.

Shading Effect of Preceding Year's Cattail Stalks on New Growth

Results

Trampling of cattails has occasionally been practiced with attendant breakage of the more advanced submersed lateral buds. It is believed that this technique accomplishes the same result as underwater mowing. As a result of these practices, as well as the annual die-back

Sprayed
6-11-52

Examined
7-16-52

Untreated control

Plot 2 left **Plot 1 right** **Plot 2 left** **Plot 1 right**

Plot 3

Plot 4

Plot 5

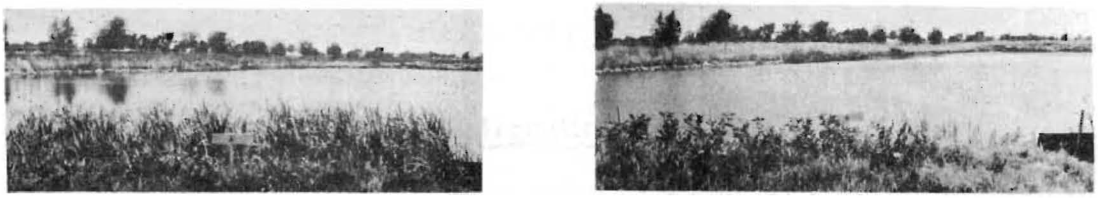
Plot 6

Fig. 35. See table 31 for a description of treatments and results illustrated on Plots 1-6

Sprayed
6-9-53

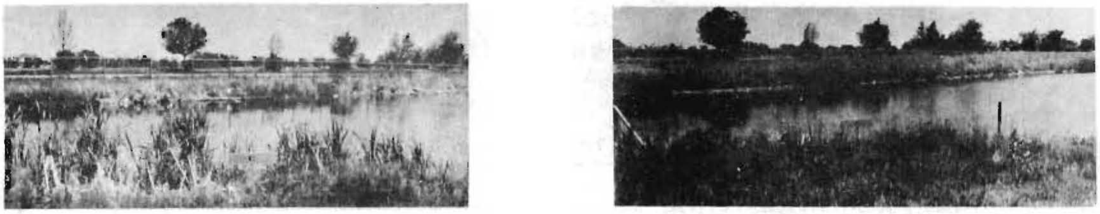
Examined
7-21-53

Untreated control



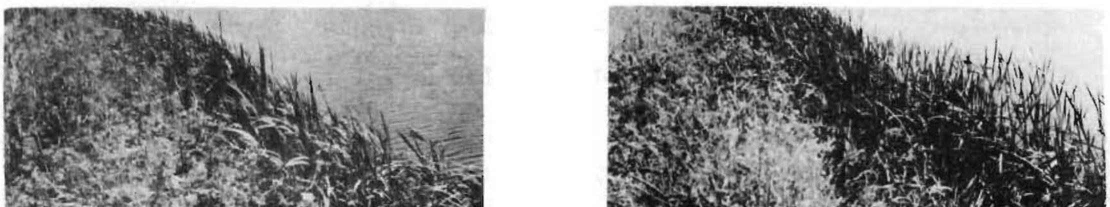
Plot A

Plot B

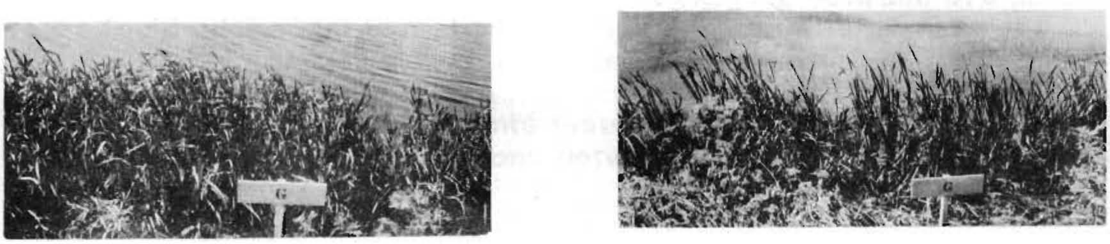


Plot C

Plot D



Plot E



Plot G

Fig. 36. See table 32 for a description of treatments and results illustrated on Plots A-G

of cattail plant tops, cattail growth areas become covered with dead leaves which interfere with the light passage to submersed aquatic plant environs, resulting in regrowth retardation. It is significant that new broad-leaved cattail growth can and will "knife" its way through the old stalk cover, if necessary, to reach light and produce growth (Figure 37).

SUMMARY

Plant Migration

Riprap grass survived and grew in water to a maximum depth of 12 inches but did not survive at greater depths. Broad-leaved cattail migrated about twice as fast as narrow-leaved cattail but produced only about half as many plants in a season's time of growth.

Control of Cattail by Livestock Grazing

The combination of eating the young cattail shoots together with mechanical injury to the plants by the hoofs of grazing cattle was sufficient to keep down cattail growth in one pasture under observation.

Water Depth Control

Marsh spike rush and ripgut grass apparently can be controlled and/or eradicated by submersing for 30 days these normally lake shore or stream bank growths with 10 and over 12 inches of water, respectively. Apparently, lowering the water line in those areas where inadequate or no subsurface irrigation exists can bring about a kill-back or permanent kill of broad-leaved cattail depending upon the length of time and time during growing season the water can be lowered.

Chemical Control

Nigrosine dye settled out of water making it ineffective as an aquatic plant herbicide.

Applications of 2,4-D on emergent aquatic species in metallic containers, simulating spray operations along canal banks, at rates varying with species predominating, effectively killed underground emergent water plant propagules with rates in general varying between 3.0 pounds per acre (acid equivalent basis) for species such as water cress and 35.0 pounds per acre for species such as awned sedge.

All emergent aquatic plants tested except broad-leaved cattail were killed with CMU concentrations between 15 and 19 ppm.

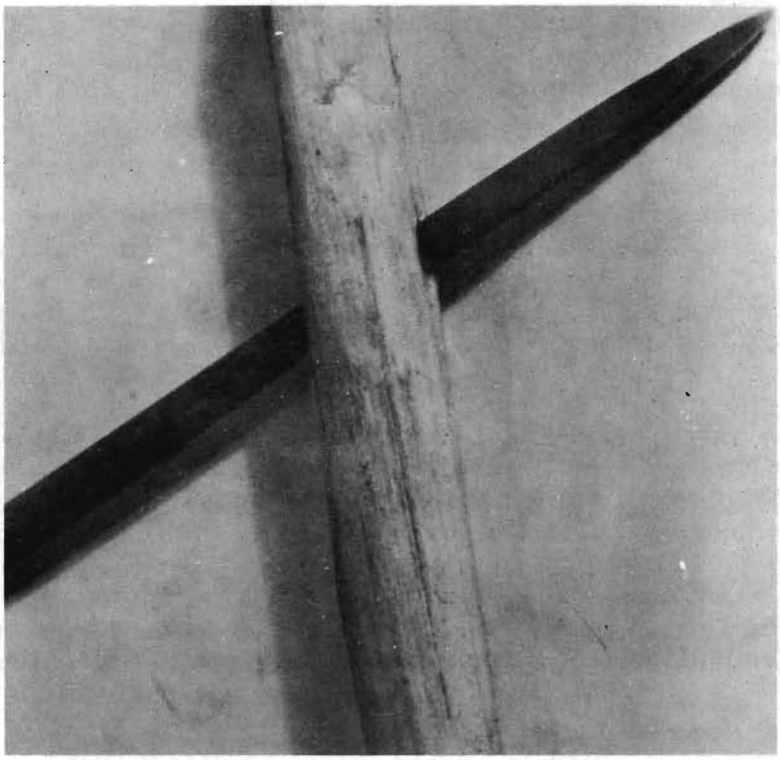


Fig. 37 New broad-leaved cattail leaf growth penetrating old stalk of preceding year's growth.

2, 4-D readily passed the water line and also accumulated in the roots.

Parrot's feather is suggested as a 2, 4-D ester vapor indicator plant useful to detect possible drift on 2, 4-D sensitive crops.

Carbohydrate Reserves in Cattail Roots

With both broad- and narrow-leaved cattails, the trend in seasonal carbohydrate root reserves varied not only with the species involved but with the growth habitat as well. In general, the period of rapid shoot growth was coincident with the period of rapid reduction in carbohydrates.

Starch in cattail rhizomes was readily used up even when the lower concentrations of 2, 4-D were applied.

Presence of trichloroacetate and tributyl phosphate was equally effective in bringing about carbohydrate reduction in cattail roots by the 2, 4-D present in the herbicidal formulations.

Application of the isopropyl ester of 2, 4-D in water at the rates of 8.7 and 13.6 pounds per acre was very effective in reducing root reserves and controlling broad-leaved cattail under field conditions. VL-600 produced very little, if any, added effectiveness to the isopropyl ester.

Observations showed that new broad-leaved cattail growth can and will penetrate old stalk cover, if necessary, to reach light.

PHREATOPHYTES--SALT CEDAR

Perhaps the greatest nuisance caused by phreatophytes growing in the southwestern part of the United States evolves from their use of water sorely needed for growing farm crops. This study was conducted for the purpose of determining the effect of various growth regulator herbicides applied at the uniform rate of 12 pounds per acre on readily hydrolyzable carbohydrates in various parts of the plants treated. A knowledge of carbohydrates remaining after 2, 4-D or 2, 4, 5-T treatment would be helpful in evaluating effect of various formulations applied.

MATERIALS AND METHODS

In connection with salt cedar field studies, treated and untreated, tree size specimens were harvested from the field with 10 inches of top attached to 10 inches of root and were delivered to the Denver laboratories for carbohydrate analyses. Sampling from submitted specimens was performed by making borings of 1-inch diameter through stem, crown, and root regions.

After the borings were made, uniform specimens from each field plot were planted in soil in metallic containers of approximately 27-gallon capacity provided with proper drainage. In many instances both field treated and untreated specimens developed luxuriant regrowth in the greenhouse producing plants up to 12 feet in height. Twenty-five of such transplanted plants were used in a replicated study designed to determine which of the systemic herbicides or herbicide combinations evaluated were most effective in reducing the carbohydrate food reserves presumably associated with kill in stem, crown, root, and rootlets of treated plants 6 weeks following herbicidal application. Chemicals evaluated were the isopropyl ester, tetrahydrofurfuryl ester, butyl ester, and amine salt of 2, 4-D, the isopropyl ester, tetrahydrofurfuryl ester, butyl ester of 2, 4, 5-T, and combinations of these. All treatments were applied August 7, 1953, at the uniform rate of 12 pounds per acre.

DISCUSSION OF RESULTS

Average carbohydrate reduction in stem, crown, root, and rootlet in greenhouse-treated and untreated salt cedar plants are presented in Table 33.

Effectiveness of the treatments were considered to be reflected in the carbohydrate reduction in the various plant parts, in decreasing order of significance as follows: rootlet, root, crown and stem.

Based solely on the reduction in carbohydrate food reserves present in the stem, crown, root, and rootlets (roots less than 1/4 inch in diameter) of treated compared to untreated specimens, the following observations were made, using the same acid equivalent poundage per acre:

Comparing isopropyl esters, 2, 4-D was more effective than an equal amount of 2, 4, 5-T.

Comparing tetrahydrofurfuryl esters, the half and half mixture of 2, 4-D, 2, 4, 5-T was most effective, the 2, 4, 5-T intermediate and 2, 4-D was least effective.

Comparing butyl esters, 2, 4-D was most effective, 2, 4, 5-T intermediate and the half and half mixture was least effective.

Comparing 2, 4-D formulations, the butyl ester was most effective, isopropyl ester was intermediate, and the tetrahydrofurfuryl ester and amine salt were about equally least effective.

Comparing 2, 4, 5-T formulations, the butyl ester was most effective, the tetrahydrofurfuryl ester only slightly less effective than the butyl ester, and the isopropyl ester was least effective.

Comparing 2, 4-D, 2, 4, 5-T and half and half mixtures of 2, 4-D and 2, 4, 5-T, the half and half mixture of 2, 4-D, 2, 4, 5-T was

Table 33--Average percent carbohydrate in stem, crown, root, and rootlet in greenhouse treated and untreated salt cedar plants 6 weeks following herbicidal application[1/]

	Stem	Crown	Root	Rootlet	No. of plants in sample
Isopropyl ester					
2,4-D	21.7	24.8	25.8	22.8	3
2,4,5-T	22.3	24.5	28.5	34.0	3
Tetrahydrofurfuryl ester					
2,4-D, 2,4,5-T	22.9	17.4	13.0	15.4	2
2,4,5-T	20.3	20.9	18.5	21.6	2
2,4-D	23.2	22.6	18.8	29.5	2
Butyl ester					
2,4-D	18.3	18.1	20.9	13.4	2
2,4,5-T	20.2	19.7	18.1	18.0	2
2,4-D, 2,4,5-T	20.9	26.8	27.3	25.9	2
2,4-D					
Butyl ester	18.3	18.1	20.9	13.4	2
Isopropyl ester	21.7	24.8	25.8	22.8	3
Tetrahydrofurfuryl ester	23.2	22.6	18.8	29.5	2
Amine salt	23.2	17.5	21.8	28.7	2
2,4,5-T					
Butyl ester	20.2	19.7	18.1	18.0	2
Tetrahydrofurfuryl ester	20.3	20.9	18.5	21.6	2
Isopropyl ester	22.3	24.5	28.5	34.0	3
2,4-D, 2,4,5-T	21.8	22.1	20.1	20.6	4
2,4-D	21.6	21.2	22.3	23.5	9
2,4,5-T	21.1	22.0	22.6	25.8	7
2,4-D, 2,4,5-T					
Tetrahydrofurfuryl ester	22.9	17.4	13.0	15.4	2
Butyl ester	20.9	26.8	27.3	25.9	2
Unprotected from 2,4-D and 2,4,5-T vapors	21.1	23.5	21.2	20.2	3
Untreated control	27.7	26.9	26.0	29.7	2

1/ Single herbicidal application of 12 pounds per acre was made August 7, 1953.

most effective; 2, 4-D was intermediate and 2, 4, 5-T was least effective.

Comparing the half and half mixture of 2, 4-D and 2, 4, 5-T, the tetrahydrofurfuryl ester was considerably more effective than the butyl ester.

It should be noted here that 1-year-old salt cedar, mesquite, and cottonwood plants were killed with ester vapors of 2, 4-D. All three plants appeared to be equally sensitive to the ester vapors. The variation in response, as measured by carbohydrate depletion when different 2, 4-D and/or 2, 4, 5-T formulations were sprayed on salt cedar, may have been similar in other tree-size weeds, e. g., mesquite, and cottonwood, had they been sprayed in like manner.

The two-spotted spider mite (red spider) (Tetranychus bimaculatus Harvey) produced heavy webbing on salt cedar growth tips. While it is regarded as a serious pest of a wide assortment of fruit trees, vegetables, berries, hops, forage crops and cattail (3), it attacks weeds including salt cedar and would seem to warrant further investigation as a biological growth deterrent of salt cedar.

It is worthy of note that salt cedar trees in the greenhouse died after a 30-day period if adequate drainage was not provided in the growing tanks. This suggests the possibility of killing salt cedar in the field by submerging the crown, where practicable, by raising water level of water storage reservoirs particularly during periods of most active growth.

SUMMARY

Based solely on the reduction in carbohydrate food reserves present in the stem, crown, root, and rootlets of uniformly treated salt cedar, various formulations of 2, 4-D, 2, 4, 5-T, and combinations of these had varying effects on the treated plants, with the butyl ester being more effective than other formulations. Too, the 2, 4-D application of this formulation was more effective than 2, 4, 5-T which in turn was more effective than the half and half mixture.

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C. Wakeland of the Bureau of Entomology and Plant Quarantine identified the two-spotted spider mite.

A. N. Steward, Department of Botany, Oregon State College, Corvallis, made the identification of awned sedge.

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