Iron Content of Selected Water and Land Plants

By EUGENE T. OBORN

CHEMISTRY OF IRON IN NATURAL WATER

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ABSTRACT

Plant roots contain a higher proportion of iron than the leaves and stems. The iron content of leaves is a function of the amount of chlorophyll present, which varies seasonally in any given species.

The iron content of lichens and water plants, on a dry basis, averaged 5.16 and 4.99 milligrams per gram of dry matter, respectively; whereas the iron content of land plants on the same basis averaged only 0.30 milligrams. The relative absence of woody tissue in the lichens and water plants probably is the reason for the difference. Soil-rooted water plants are effective in removing iron from submerged soils, and the water-rooted types also seem to be effective in removing iron from the water. The iron content of the soil-rooted type is about 3 to 7 times as great as that of the water-rooted type. The iron content for plants growing in rock, soil, and water environments agrees in general with published data.

INTRODUCTION

Aquatic plants, both microscopic and macroscopic, through respiration, photosynthesis, and protoplasm metabolism, are vital in determining not only if iron will be present in water but also what form and amount of iron can exist in solution. Aquatic plant-iron relations are complicated because some plants, such as plankton, extract iron directly from the water, whereas other plants, such as most benthonic forms, extract iron mainly or totally from submersed soil in which the plants are rooted.

Iron is not transferred from leaf parts of a plant to other growing tissues of the same plant. New leaves which develop from actively growing rhizomes, seeds, tubers, vegetative tussock, or fragment plant parts lacking in iron would be deficient in chlorophyll and thus indicate that iron is unavailable to the plant. Mechanisms by which iron is absorbed and transported in plants are not fully known (Meyer and Anderson, 1948). Nevertheless, the literature indicates that generally upon immediate entry into plant cells, iron enters into organic combination and is reduced (Oborn, 1960). Apparently, discrepancies in the reported degree and rate of absorption of the different forms of iron, as in diatoms, may actually reflect differences in efficiency of the processes involved in reducing iron to the ferrous state (Correns, 1941; Harvey, 1939).

PURPOSE

The role of aquatic vegetation in bringing iron into solution or in removing dissolved iron from surface water has been studied as part of research on chemistry of iron in natural water by the Geological Survey. Before aquatic vegetation could be tested, however, some information was needed on the iron content of different species and the amount contained in different plant parts. Samples of aquatic plants were collected and analyzed in the laboratory to provide this information. For comparison, a few varieties of land plants and lichens were also studied.

OCCURRENCE OF IRON IN PLANT MATERIALS

Proportionately large amounts of chlorophyll and associated iron occur in aquatic plants because the epidermis commonly contains chloroplasts and forms a large part of the photosynthetic tissue of the leaves. The finely divided, long, thin, radial, cylindrical, terete leaves of aquatic plants are green over their entire surface. Stems of most such plants are green and consist either of an abbreviated axis bearing a tuft of long, narrow leaves or of thin, elongated branches that rise into the water and that are clothed with leaves. Even the roots in free-floating water plants may be green.

In submerged tissues of hydrophytes, a comparatively small amount of woody protecting, supporting, or conducting tissue is needed. In many water plants, cellulose and lignin growth which normally is prominent in land-plant cell-wall thickening is present in lesser amounts; in others, woody tissues may be entirely lacking, and a well-defined cavity marks the normal position of the wood. This situation results in a large proportion of living protoplasm (and therefore protein) being present in aquatic plants (Escudero and others, 1944; Gortner, 1934; Harper and Daniel, 1934). Iron is essential for most and probably all protoplasm synthesis because it is an integral part of respiratory pigments such as cytochrome; hence, water plants should have more iron present per unit of ash than land plants. Read and Gow (1927) found certain seaweed and fresh-water blue-green algae to be remarkably rich in iron, as well as in other minerals. Because rock plants also are devoid of woody tissues, they also should have more iron present per unit of ash than land plants.

Although emphasis in this report has been placed on plant biochemistry, Bonner (1950) points out that much of biochemistry is common to many kinds of living things and that some metabolic processes used by, perhaps, a microorganism may also be used by higher animals and plants. Therefore, the metabolic processes that involve iron are significant in the occurrence of iron in natural water.

NONTECHNICAL DEFINITION OF TERMS

The following selected biological terms are defined to facilitate the reading of this study by others in related fields:

Anabolism. The building up or constructive phases of metabolism.

Benthos. Organisms that inhabit the bottom of a lake or other water body.

Culm. Stemlike part of sedges.

Hydrophyte. Water plant.

Lichen. A fungus and an alga growing cooperatively together as an individual plant entity.

Plankton. Forms of life, frequently microscopic, near surface of open water.

Rhizome. An underground plant stem having rootlike functions.

Vascular plant. Plant having a vessel or vessels for conveyance of sap through the plant; mainly these are flowering plants, but include the ferns.

Vegetative tussock. Tuft or clump of young plants.

MECHANISMS BY WHICH PLANTS AFFECT IRON CONTENT OF WATER

Organic acids, such as humic or tannic acid, stimulate the growth of algae in lakes. One reason for the growth stimulation seems to be the complexing action of these organic acids derived from disintegrated aquatic plant material (Birge and Juday, 1926; Butcher, 1933; Nierenstein, 1945; Pond, 1903; Rummeni, 1955) which keeps iron in solution even at a pH as high as 9.5 (Shapiro, 1958; Hem, 1960).

DeGruchy (1938) has reported on the ability of aquatic plants to increase or decrease mineral content of water.

Although the simpler forms of plankton excrete directly to the surrounding water medium, the more complex plants often deposit insoluble food substances in special cells, which may be returned to the soil with other dead plant material. Agricultural soils normally support a bacterial population of 1 million to 50 millions per gram of soil and a fungal population of 500,000 to 1 million per gram of soil (Yust, 1951) as well as fewer algae and protozoa. Under optimum conditions of moisture and temperature, these microorganisms disintegrate iron-rich plant cells, which makes the iron available for solution in natural water.

Much of the dissolved iron in water bodies passes through a cycle somewhat like the cycles for carbon, sulfur, and nitrogen. A knowledge of the iron content of representative plant materials, particularly of water and also of land species, is desirable. Other current studies show that plant material having high iron content—for example, *Chara*, *Cladophora*, and *Potamogeton* (see table 4)—at optimum microbial incubation temperatures does release, through leaching, large amounts of iron into natural water; whereas plant material having low iron content—for example, *Convolvulus*, *Populus*, *Typha*—at optimum microbial incubation temperatures releases small amounts of iron into natural water.

Conversely, aquatic plants in photosynthesis and assimilation may remove dissolved iron and presumably other minerals from the water body in which they grow. Precipitated minerals can seal the surface of soil under continuous submergence (Hayward and Magistad, 1956).

On a given cropland area, plant transpiration is particularly effective in increasing the mineral concentration of soil solutes. Water loss through soil-surface evaporation, though of lesser magnitude, also adds to the mineral concentration of the soil solutes (Eaton, 1954).

Closer study of the liaison between living organisms and their encompassing water medium should result in an improved understanding of the many varied and interrelated biochemical processes.

The dry weight of certain aquatic plants, the proportions of ash in dry matter and of iron in ash, and the amount of iron that can be extracted by acid from soil in which the plants grow have been determined in this work; the results are needed for proper interpretation and evaluation of other current related studies.

TYPES OF PLANTS STUDIED

In order to evaluate the relative effectiveness with which aquatic plants extract iron from the water and (or) the under-water soil medium in which they may be rooted, plants from diverse habitats were included. Some, such as spinach and parsley, have been reported by West and Todd (1955) to be good sources of food iron. The plants analyzed in this study for their iron content are classified according to their natural growth habitat as follows:

Classification of plants according to their natural growth habitat

Habitat	*Plant*
Rock	Crustose lichens growing in the absence of soil.
Rock-soil	Foliose lichens and black moss growing in the presence of soil formed by crustose lichens.
Land	Assortment of plants that require well-drained soils for optimum growth. This group includes not only several plants that are troublesome weeds but also plants that are recommended for the human diet because of their high iron content.
Land-water	Plants that are generally confined to areas where an abundant supply of water is available but where the soil is not completely saturated. This group includes the phreatophytes (Robinson, 1958). Land-water plants are divided into the following two groups: *Herbs.* Plants having nonwoody parts *Shrubs and trees.* Plants having woody parts
Water	Plants whose roots and (or) rhizomes may be completely immersed in water or buried in water-saturated unaerated mud for prolonged periods with no apparent injury to the plant. Water plants are divided into those which grow emergent, and those growing submersed, with either water roots or soil roots: *Emergent.* Plants whose bodies mostly protrude above the surface of the water. *Water roots.* Plants whose roots or rootlike organs are not attached to the water-submersed soil. Minerals, including iron, are directly absorbed from the water. *Soil roots.* Plants whose roots or rootlike organs are attached to the water-submersed soil. Minerals, including iron, are absorbed principally or entirely from the water-submersed soil. *Submersed.* Plants whose bodies mostly do not protrude above the surface of the water. *Water roots.* See *Emergent* above. *Soil roots.* See *Emergent* above.

This ecological plant classification is inexact, but it is useful for this investigation.

COLLECTION AND SELECTION OF MATERIAL FOR STUDY

The species of plants investigated include many that grow in, along, and adjacent to lakes, streams, and open-water distribution systems west of the 100th meridian in the United States. Most of the plants investigated were identified in the Denver laboratory of the Geological Survey. Gray's Manual of Botany (Fernald, 1950) was used for the classification and nomenclature of most of the vascular plants.

For the Boston fern, nomenclature in the Boston Flower Market and the New England Florist (Boston Flower Market and New England Florist, 1896; Davenport, 1896) was used. E. S. West of the

University of Florida Botany Department provided the nomenclature for alligatorweed. R. A. Pursell and S. Shushan of the University of Colorado Biology Department identified the black moss and the lichens. The classification and nomenclature of the algae are based on the work of Smith (1950). Descriptions by Ellis (1919) were used to identify the iron bacteria.

Whole plants were used in most of the analyses. For the woody plant, alfalfa, the "whole" plant consisted of the parts growing above ground and 3 inches of the root. When analysis of the whole plant was impractical because of large size, only the leaves were used. Both the leaf and the root-rhizomes of the cattails were analyzed, but only the culm of the bulrush was used. Fern fronds were collected from a potted household plant. All the lichens and black moss were collected in July 1957 near Gunnison, Colo. The red, yellow, and gray crustose lichens were scraped from the same large rock. The foliose lichens and black moss were growing in the dirt-filled crevices of the same rock; the black moss requires much more soil than foliose lichen for growth.

Some saltcedar specimens that were a deeper, more brilliant green than most of the others were observed in the John Martin Reservoir area near Lamar, Colo., in September 1957. Handshovel excavation showed that iron deposits were intermingled with the roots of the deeper green specimens but were lacking near the dull-green specimens. Contrasting leaf shades associated with utilization of different amounts of soil iron by two saltcedar trees is illustrated in plate 1. More abundant iron appears to make trees more resistant to organic leaf defoliants (H. F. Arle, written communication, 1959).

Soil samples were removed from the areas in which these two different growth aspects occurred. For comparison, soil samples from the muck bottom of the Federal Center lake (Denver, Colo.) were obtained. Pondweeds and other aquatic plants grow profusely in the Federal Center lake each growing season. A surface sample of Federal Center soil, in which the land plant crested wheatgrass (*Agropyron cristatum* (*L.*) Gaertn), grows well, was also obtained.

PROCESSING AND STUDY OF MATERIAL

All harvested plant material was first washed and then thoroughly rinsed twice with distilled water to remove any salt and dust particles from leaf and other plant body surfaces. The plant material was then spread out on a table and blotter dried to approximate the moisture condition of the plant material before being washed. The material was cut with scissors into pieces not exceeding one-quarter inch in length. Approximately 70 milliliters of comparable

CONTRASTING SALTCEDAR GROWTH ASSOCIATED WITH DIFFERENT AMOUNTS OF IRON IN SOIL

Tree *b*, where soil contains more iron, has darker leaves and heavier foliage than tree *a*

and representative duplicate chopped plant parts was placed in each of 2 porcelain dishes.

Separation of the lichens, particularly the crustose lichens, from sand grains was expected to be difficult. However, the lichens were washed and blotter dried, and after they were stored between blotters for 10 days, the sand grains had separated and fallen away from the lichen tissue.

The two genera of algae and iron bacteria were identified with the microscope, and the algae were physically separated by hand processing.

Each of the soil samples was ground with a mortar and pestle and passed through a 2,000 micron no. 10 (Am. Soc. Testing Materials Standards, 1957) sieve. Approximately 1 gram of soil sample was placed in each of 2 porcelain dishes for moisture determination.

Determinations of dry material, total ash, and iron in ash were made on each sample, including the soil samples. The methods and procedures suggested by Lepper (1950) and Woodman (1941) were followed. Duplicate samples were used throughout, and averages of the duplicate samples are reported in the results.

DRY-MATERIAL DETERMINATION

Approximately 70 milliliters of fresh, washed, blotter-dried, chopped plant material was placed in duplicate 70-milliliter capacity porcelain dishes and rapidly weighed. Where applicable, about the same amount of each plant part—for example, leaf, stem, or root—was placed in each of the duplicate dishes. About 1 gram of soil was used in each determination made on the soil samples.

After weighing, all samples were placed in a drying oven, maintained at 100°C, for 30 minutes to inactivate any plant enzymes present (Miller, 1938). The samples were then transferred to a drying oven, maintained at 62°C, and the plant material was heated to constant weight. At the end of 3, 5, 7, and 10 days of heat treatment the samples were brought to room temperature and then weighed. After 10 days' heat treatment, all samples had reached constant weight, which was taken as the final weight.

TOTAL-ASH DETERMINATION

The dried samples were ignited gently over a small flame until thoroughly charred (Woodman, 1941). The dishes were then placed in a muffle and heated to low redness (575°C) until a uniform white, gray, or occasionally reddish or green ash, free from fused lumps or particles of unburned carbon was obtained. The samples were cooled overnight in a desiccator and weighed.

IRON IN ASH

Fairly close agreement between the amount of iron reacting with bipyridine reagent and the biologically available iron has been noted in many foods (West and Todd, 1955). The bipyridine method (Rainwater and Thatcher, 1960) uses the reaction between ferrous iron and α,α' bipyridine, which yields a red complex, and has been used throughout this research. The interference of tannic acid complexes has been noted by Hem (1960), and interference of other strong organic complexes is probable. However, such interferences are irrelevant to these experiments because the organic matter was destroyed in the ashing of the sample.

The ash was moistened (Lepper, 1950; Woodman, 1941) with 5 milliliters of hydrochloric acid, and the mixture boiled for 2 minutes. Approximately 50 milliliters of water was added, and the sample heated on the steam bath for about 30 minutes. The sample was then filtered through a hardened low-ash filter paper and thoroughly washed. The filtrate was increased to 200 milliliters with water. The remainder of the procedure followed that generally used for water samples.

Because the same sampling and analytical procedures were followed on all samples, results of analyses are comparable and indicate the iron content per unit of ash or dry matter for the various diversified plant categories.

RESULTS

Different sampling and procedures in plant analysis sometimes make comparison of published results difficult. In interpreting data, variables that may be inherent in sampling and analytical procedures must be considered. In another report, Oborn and others (1954) have shown that in general through the growing season, leaves of broad- and narrow-leaved cattail (*Typha latifolia* L. and *T. angustifolia* L.) increase in percentage of dry matter from initial spring growth to the time of killing frost. Conversely, rhizomes and roots of these same plants have the highest percentage of dry matter during plant dormancy and a low percentage about the first part of June at the altitude and in the latitude of Denver, Colo. These facts suggest that the proportions of dry matter and, therefore, the amount of mineral salts, including iron, differ throughout the growing season not only among species but also in different plant parts.

An ash determination that included the whole plant would show a higher percentage of ash than a determination that included only the leaves. Also, ash and, therefore, iron content of any given plant or plant part would apparently depend on the part of the growing season—such as before flowering and after fruiting when harvest was made. A leaf harvested after fruiting would have an iron content different from that of a leaf harvested before flowering. Pesek (written communication, 1958) has reported similar observations from work done in Tennessee with alfalfa. These and other variables must be recognized if plant analytical data are to be evaluated in proper perspective.

In table 1, some results of iron and ash determinations made in this study are compared with results from other sources for similar plant material. Watercress is the only aquatic plant in which iron content has been reported by others. The results of most of the

TABLE 1.—*Iron and ash in plant materials*

Name of plant	Common name	Plant part tested	Milligrams iron per 100 g fresh plant material	Percent ash (fresh tissue basis)
Taraxacum officinale Weber.	Dandelion	Greens	[1] 3.1	[2] 2.0
		Greens (including 3 in. of root).	[3] 4.4	[3] 1.9
Brassica oleracea L. var. *broccoli* L.	Broccoli	Flower stalks, raw	[1] 1.3	[2] 1.1
		Flower stalks (including stem and leaves).	[3] 1.0	[3] 1.8
Petroselinum crispum (Mill.) Mansf.	Parsley	Leaf, raw	[1] 4.0	[2] 2.4
		do	[3] 5.2	[3] 2.4
Spinacia oleracea L.	Spinach	do	[1] 3.0	[2] 1.5
		do	[3] 1.9	[3] 2.1
Nasturtium officinale R. Br.	Watercress	Leaf and stem, raw.	[1] 2.0	[2] 1.1
		Whole plant.	[3] 19.0	[3] 1.2
Medicago sativa L.	Alfalfa	Leaf and stem	[4] 2–4	
		Leaf and stem, (including 3 in. of root).	[3] 3.4	[3] 2.1
Cynodon dactylon (L.) Pers.	Bermuda grass	Whole plant	[5] 15.0	
		do	[3] 13.3	[3] 2.7
Vitis vinifera L.	Thompson seedless grape.	Fruit (raisin)	[6] 3.3	
		do	[3] 2.6	[3] 2.18

[1] From Bowes and Church (1952).
[2] From McLester (1946).
[3] Denver laboratory data.
[4] From Stanford, E. H., Calif. Univ., Davis, Calif. (written communication, 1958).
[5] From Spector (1956).
[6] From Alley, C. J., Calif. Univ., Davis, Calif. (written communication, 1958)

iron and ash analyses from the Denver laboratory agree closely with those from other sources. The main discrepancy is in the iron reported for watercress and may be the result of testing different plant parts in the analyses.

In table 2, some results of dry matter and ash determinations made in this study of plant materials are compared with results from other sources. The results agree as closely as can be expected considering the different plant parts used and the uncertainty of the composition of Gortner's mixed random plant sample. The comparisons in tables 1 and 2 indicate that methods used in this study give results that agree in general with the published work of others.

TABLE 2.—*Dry matter and ash in plant materials*

Name or type of plant	Common name	Plant part tested	Percent dry matter	Percent ash (dry tissue basis)
Potamogeton pectinatus L.	Sago pondweed	Leaf and stem	[1] 15.0	[1] 13.0
		Whole plant	[2] 9.9	[2] 19.0
Medicago sativa L.	Alfalfa	Leaf and stem	[3] 20–33	[1] 9.4
		Leaf and stem (including 3 in. of root).	[2] 23.5	[2] 8.5
Water submersed (mixed random plant sample).		Leaf and stem	[1] 15.8	[1] 15.4
		Whole plant	[2] 11.2	[2] 19.9

[1] From Gortner (1934).
[2] Denver laboratory data.
[3] From Stanford, E.H., Calif. Univ., Davis, Calif. (written communication, 1958).

Percentages of air-dried soil remaining after oven drying and igniting and of iron found in four soil samples are presented in table 3. The soil having the highest iron content supported the lush saltcedar (*Tamarix gallica L.*) growth. See plate 1. Available iron in the soil is necessary for chlorophyll synthesis by the green plant (Bonner, 1950). Evidently, iron is abundantly available to the lush aquatic plant growth in the Federal Center lake at Denver, Colo. Soil from the lake bottom is high in iron and contains much organic matter that is driven off when the soil sample is heated to 575°C. The organic matter may help to make iron available by complexing or influencing pH and Eh of the soil solution (Birge and Juday, 1926; Butcher, 1933; Keller, 1955; Nierenstein, 1945; Pond, 1903; Rummeni, 1955; Schatz and others, 1956). None of the soils studied are deficient in iron.

Plants require iron to produce chlorophyll. Without available iron, green plants quickly become chlorotic. Therefore, the amount of chlorophyll-bearing tissue should be related to iron content in plants.

TABLE 3.—*Nonvolatile matter and iron content of soils*

Sample	Vegetation growing on soil	Date (1957)	Percent nonvolatile matter (air-dried sample=100)		Percent iron in nonvolatile matter at 575° C
			At 62° C	At 575° C.	
1	Saltcedar, lush, deep green	July 23	97.6	94.3	4.42
2	Saltcedar, regular, light-green growth	do	98.3	95.3	2.43
3	Crested wheatgrass	Sept. 30	98.3	92.9	3.68
4	Lush abundant growth, Federal Center Lake bottom	do	97.6	82.2	4.20

Figure 18 shows cross sections of photosynthetic regions of four plants whose iron content is reported in table 4. Chlorophyll is represented by shading within the individual cells. In 2 diverse iron-metabolizing aquatic plants (figs. 18*A* and 18*B*), pond scum has 100 percent and waterweed approximately 90 percent of chlorophyll-bearing tissue. This high percentage of constructive anabolic tissue, largely confined to the epidermal area or the equivalent of this area, results from an expanded plant body surface for plant food manufacture.

Epidermal tissue of land plants (fig. 18*C*) does not produce chlorophyll. The chlorophyll-bearing tissue may amount to less than 80

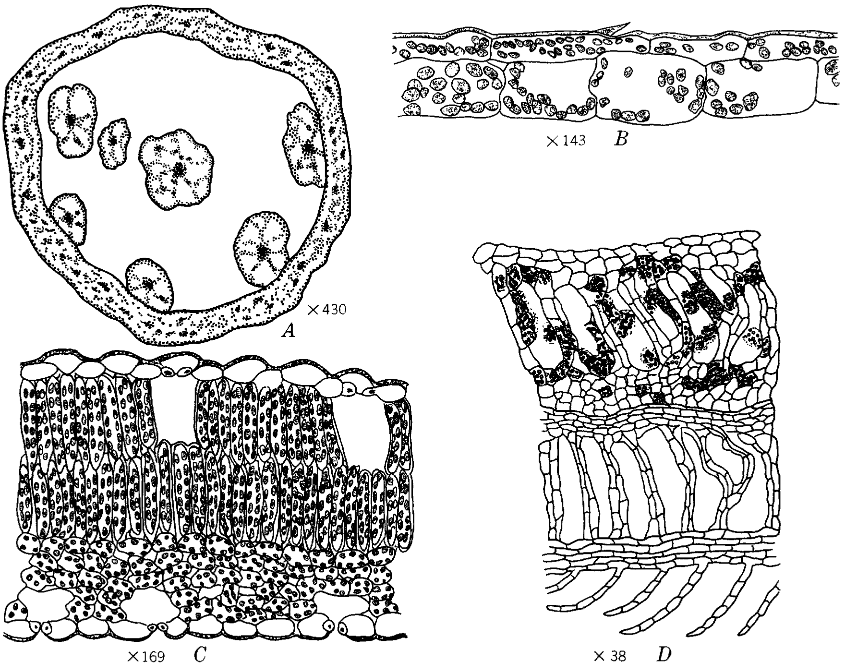

FIGURE 18.—Cross sections of representative plant parts. Chlorophyll in cells represented by shading. *A*, Pond scum filament (water-submersed, water-rooted); *B*, waterweed leaf (water-submersed, soil-rooted); *C*, Alfalfa leaf (land plant); *D*, foliose lichen thallus (rock-soil plant).

TABLE 4.—*Dry matter, ash, and iron content of different types of plants*

Type of plant	Name of plant [1]	Common name	Plant part tested	Condition of growth	Date of harvest	Percent plant constituents			Milligrams of iron per gram of dry matter
						Dry matter	Ash in dry matter	Iron in ash	
Rock	*Lecanora rubina* (Vill.) Ach	Crustose lichen. gray.	Whole plant		July 16, 1957	92.2	20.2	1.93	3.89
	Candelariella spraguei (Tuck.) Zahlbr.	Crustose lichen. yellow.	do		do	93.2	14.4	2.30	3.32
	Gasparrinia elegans (Link) Stein apud Cohn.	Crustose lichen. red.	do		do	88.7	13.1	3.83	5.02
Rock-soil	*Parmelia conspersa* (Ehrh.) Ach	Foliose lichen. gray	do		do	31.2	25.7	1.24	3.18
	Grimmia apocarpa Hedw	Black moss	do	Fruiting	do	17.6	26.2	3.97	10.4
Land	*Brassica oleracea* L. var. *broccoli* L.	Broccoli	Leaves, stems, flower primordia.	Before flowering [3]	Oct. 2, 1957	14.7	12.0	.06	.07
	Convolvulus arvensis L	Bindweed	Whole plant	Before flowering	do	20.4	10.6	.50	.53
	Cynodon dactylon (L.) Pers	Bermuda grass	do	do	do	27.6	9.71	.50	.48
	Malva rotundifolia L	Round-leaved mallow.	do	Fruiting	do	16.0	15.4	.18	.25
	Medicago sativa L	Alfalfa	do.[2]	Flowering-fruiting	July 26, 1957	23.5	8.52	.17	.14
	Nephrolepsis exaltata L. Schott. var. *Bostoniensis* Davenport.	Boston fern	Leaf	Before fruiting	July 16, 1957	20.4	12.2	.10	.12
	Petroselinum crispum (Mill.) Mansf.	Parsley	do	Before flowering [3]	Oct. 2, 1957	13.4	17.6	.22	.39
	Spinacia oleracea L	Spinach	do	do	do	11.6	18.3	.09	.16
	Taraxacum officinale Weber	Dandelion	Whole plant	After fruiting	do	12.5	14.9	.24	.36
	Tribulus terrestris L	Puncturevine	do	Flowering-fruiting	do	22.6	16.1	.18	.28
Land-water:									
Herbs	*Carex aquatilis* Wahlenb	Water sedge	do	After fruiting	do	32.4	7.99	1.18	.94
	Eleocharis palustris (L.) R. and S.	Marsh spikerush	do	do	do	18.6	20.5	1.30	2.64
Shrubs-trees	*Populus deltoides* Marsh	Cottonwood	Leaf	do	July 25, 1957	30.5	9.77	.06	.06
	Populus balsamifera L	Balsam poplar	Root (rotted)	do	July 16, 1957	88.7	22.9	.34	.77
	Tamarix gallica L	Saltcedar	Leaf	Flowering	July 23, 1957	30.3	15.2	.26	.40

See footnotes at end of table.

TABLE 4.—*Dry matter, ash, and iron content of different types of plants*—Continued

Type of plant	Name of plant [1]	Common name	Plant part tested	Condition of growth	Date of harvest	Percent plant constituents: Dry matter	Percent plant constituents: Ash in dry matter	Percent plant constituents: Iron in ash	Milligrams of iron per gram of dry matter
Water:									
Emergent:									
Water roots	*Lemna minor* L	Smaller duckweed	Whole plant	Fruiting	July 22, 1957	6.2	17.5	0.14	0.24
Soil roots	*Alternanthera philoxeroides* (Mart.) Griseb.	Alligatorweed	do	Flowering	July 23, 1957	21.3	7.00	1.56	1.08
	Eichornia crassipes (Mart.) Solms	Water-hyacinth	do	After fruiting	Oct. 2, 1957	5.3	19.6	.25	.49
	Myriophyllum brasiliense Camb	Parrot's feather	do	Before flowering	July 23, 1957	25.8	13.5	.97	1.30
	Nasturtium officinale R. Br	True watercress	do	do	do	6.7	18.1	1.57	2.85
	Scirpus acutus Muhl	Hard-stem bulrush	Culm	Fruiting	Oct. 2, 1957	69.1	9.26	.08	.07
	Typha angustifolia L	Narrow-leaved cat-tail.	Leaf	After fruiting	July 26, 1957	23.1	9.56	.05	.04
			Rhizome-roots	Dormant	Feb. 21, 1958	16.1	6.21	7.14	4.43
	Typha latifolia L	Broad-leaved cattail	Leaf	After fruiting	July 26, 1957	27.8	8.08	.06	.05
			Rhizome-roots	Dormant	Feb. 21, 1958	14.0	6.03	4.27	2.55
Submersed:									
Water roots	*Cladothrix* Cohn, *Leptothrix* Kützing.	Iron bacteria	Whole plant	Vegetative	May 29, 1957	6.1	44.0	.10	.42
	Leptothrix Kützing	Iron bacteria	do	do	Oct. 12, 1957	23.9	70.1	19.3	135
	Cladophora sp. Kützing	Pond scum	do	do	July 23, 1957	17.2	22.1	.97	2.13
	Spirogyra sp. Link	Pond scum	do	do	do	14.4	20.7	1.52	3.14
Soil roots	*Eleocharis acicularis* (L.) R. and S.	Needle spikerush	do	Fruiting	do	15.0	46.4	.69	3.19
	Elodea densa (Planch.) Caspary	Dense waterweed	do	Before flowering	do	12.2	15.2	4.63	7.03
	Elodea nuttallii (Planch.) St. John	Western waterweed	do	do	do	10.3	16.2	4.25	6.90
	Heteranthera dubia (Jacq.) MacM.	Water stargrass	do	After flowering	do	7.2	15.6	.35	.54
	Potamogeton foliosus Raf. var. *macellus* Fern.	Meagre leafy pondweed.	do	Fruiting	July 22, 1957	18.1	9.23	.44	.40
	Potamogeton nodosus Poir	American pondweed.	do	do	do	14.0	9.67	.59	.57
			Leaf	do	do	16.8	10.0	.27	.27
	Potamogeton pectinatus L	Sago pondweed	Whole plant	Before flowering	July 23, 1957	9.9	19.0	7.98	15.1
	Potamogeton richardsonii (Ar. Benn.) Rydb.	Redhead pondweed	do	do.[4]	Oct. 2, 1957	8.7	17.6	4.84	8.50
			do	After fruiting	July 23, 1957	7.0	21.7	2.54	5.55
	Sagittaria subulata (L.) Buchenau	Dwarf arrowhead	do	Before flowering [4]	do	5.8	22.9	6.66	15.3
	Zannichellia palustris L	Horned pondweed	do	do.[4]	Oct. 2, 1957	6.1	21.7	10.1	22.0

[1] All lichen identifications by S. Shushan, Colo. Univ. Moss identification by R. A. Pursell, Colo. Univ. Remainder of identifications by the author.
[2] Parts above the ground and 3 in. of the root.
[3] From store.
[4] Rootstocks of this sample were planted and grown in greenhouse culture tanks. Although the harvest date was late, there had been no fruiting during growth; therefore, this harvest should be classified as before flowering.

percent of the plant leaf in many species. Lichens (fig. 18*D*) consist entirely of algae and fungi living in symbiotic relationship. The chlorophyll-bearing tissue is proportionately less in lichens than it is in either aquatic or land plants. Embryonic regions of growth that require iron in aquatic and lichen plants appear to be somewhat similar. Crustose lichens should have proportionately more chlorophyll-bearing algal tissue than foliose lichens because of relatively greater surface exposed.

How lichens and aquatic plants remove iron from the substrata to which they are rooted and how aquatic plants remove iron from the immersing water medium have been discussed in another paper (Oborn, 1960) and needs no further elaboration here.

Amounts of dry matter, ash, and iron found in the plants studied are presented in table 4. Iron in ash and in dry matter are several times higher in the rotted roots of balsam poplar than in the leaves of cottonwood poplar. Of course, these trees are of different species, but the comparison seems justified because they are of the same genus and have the same growth habitat. The difference between iron contents of root and leaf is even greater for the two cattail species. In the water-submersed soil-root type of plants, as exemplified by the American pondweed, there is slightly more dry matter and ash in the leaves than in the whole plant, whereas the iron content of ash and dry matter is about half as great in the leaves as in the whole plant.

The duplicate specimens of redhead pondweed harvested July 23, 1957, gave 1.85 and 3.22 percent of iron in the ash (average 2.54 percent given in table 4). The duplicates were designed so one of the samples would have more tops, the other more roots. The higher iron content for the sample having more roots emphasizes the importance of having, so far as is practical, the same kind of plant parts in duplicate samples if comparable results are to be expected. Results for this species of plant show that time of harvest with respect to the life cycle affects the amount of iron in plant tissue. Because of proportionately larger amounts of protein present the plants harvested before flowering (see footnote 4 in table 4) had approximately twice as much iron per gram of ash and per gram of dry matter as did the same species harvested after fruiting.

Iron bacteria, here considered to be a submersed water-root type of plant, vary widely in the amount of iron present per unit of ash. Ellis (1919) has indicated that iron bacteria may deposit iron deposits equal to 12 times or more the width of their filaments. Microscopic examination of some of the iron bacteria harvested October 12, 1957, corroborated the findings of Ellis. However, microscopic examination of the iron bacteria harvested on May 29, 1957, showed no noticeable deposits.

Because of the variability in the iron present in or, more properly, deposited by the iron bacteria (see fig. 19), this group was not included in calculating any of the averages recorded in table 5.

TABLE 5.—*Average analyses for types of plant and plant parts tested*

Summary	Type of plant	Plant part tested	Percent plant constituents: Dry matter	Percent plant constituents: Ash in dry matter	Percent plant constituents: Iron in ash	Milligrams of iron per gram of dry matter
A	Land	Leaf-culm	15.1	16.1	0.14	0.22
	Land-water	do	30.4	12.5	.16	.23
	Water-emergent:					
	Soil-roots	do	40.0	8.97	.06	.05
	Do	Rhizome-roots	15.0	6.12	5.70	3.49
	Water-submerged:					
	Soil-roots	Leaf-culm	16.8	10.0	.27	.27
B	Rock	Whole plant	91.4	15.9	2.69	4.08
	Rock-soil	do	24.4	26.0	2.61	6.79
	Land	do	19.6	12.5	.26	.30
	Land-water	do	25.5	14.3	1.24	1.79
	Water-emergent:					
	Water-roots	do	6.2	17.5	.14	.24
	Soil-roots	do	14.8	14.6	1.09	1.43
	Water-submersed:					
	Water-roots	do	15.8	21.4	1.25	2.64
	Soil-roots	do	10.4	19.6	3.92	7.73
C	Water-emergent (including land-water type)	Leaf-culm	36.2	10.4	.10	.12
	Water-submersed	do	16.8	10.0	.27	.27
D	Water-emergent (including land-water type)	Whole plant	16.6	14.9	1.00	1.36
	Water-submersed	do	11.2	19.8	3.51	6.95
E	Rock (including rock-soil type)	do	64.6	19.9	2.65	5.16
	Land	do	19.6	12.5	.26	.30
	Water (including land-water type)	do	13.1	18.1	2.63	4.99

Except for iron bacteria, the highest iron content in the water plants is reported for horned pondweed (*Zannichellia palustris* L.). Sago pondweed (*Potamogeton pectinatus* L.) also contains much iron. The evolution of long thin cylindrical leaves has greatly increased the surface of these two plants. Figure 20 *A* is a cross section of such a leaf showing the high proportion of cells containing chlorophyll. Large amounts of iron are also contained by the water-submersed soil-rooted plants which have large thin leaf blades. Figure 20 *B* shows the tissue arrangement in leaves of waterweeds (*Elodea* sp.), redhead pondweed (*P. richardsonii* (Ar. Benn.) Rydb.), and dwarf arrowhead (*Sagittaria subulata* (L.) Buchenau) where the leaf tissue is reduced to two epidermal layers. The low iron content of water stargrass (*Heteranthera dubia* (Jacq.) MacM.) seems to relate to the I-beam type of leaf structure shown in figure 20 *C*. Both broad- and narrow-leaved cattail leaves also have this I-beam type of leaf structure, and data in table 4 show that these leaves are low in iron content.

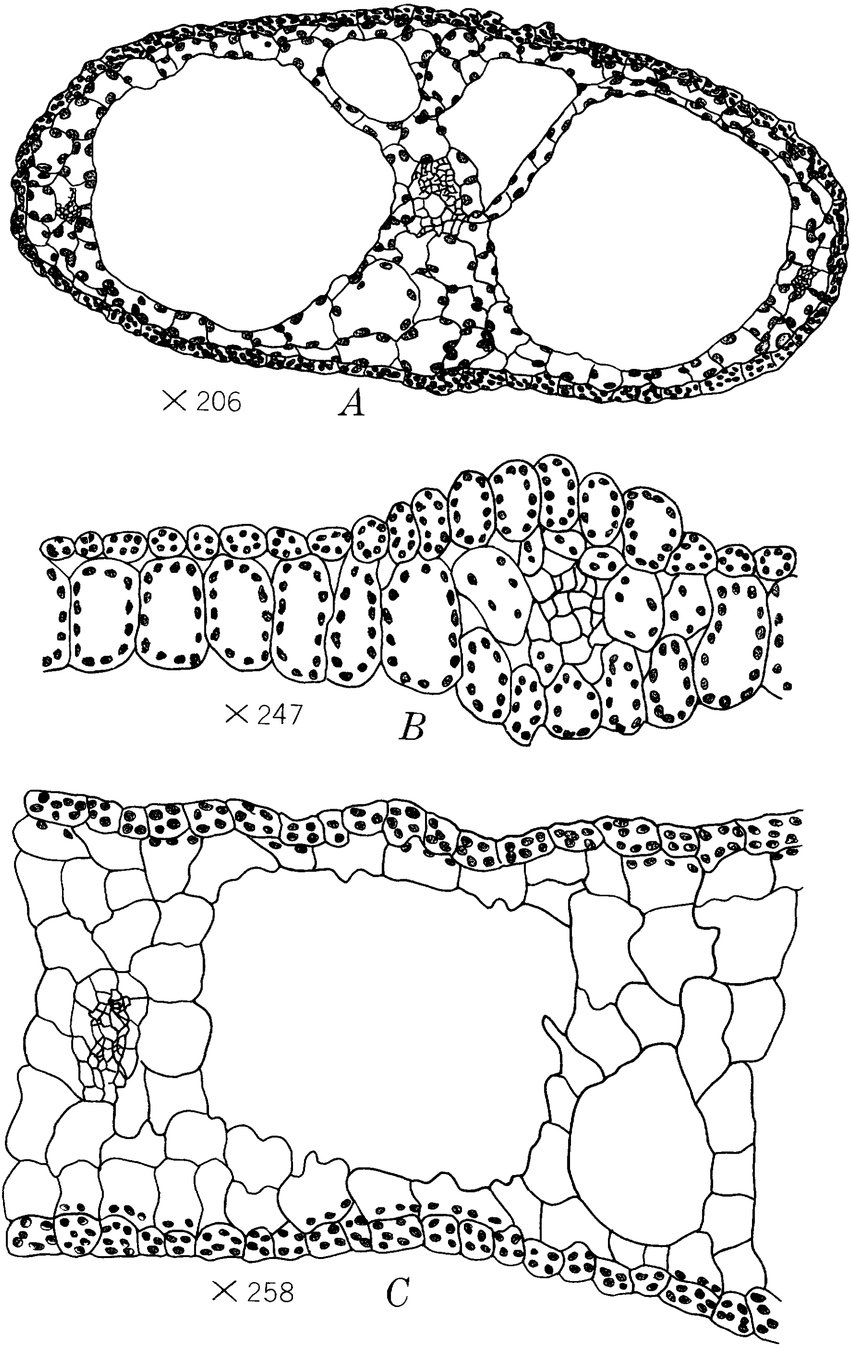

FIGURE 19.—Lateral view of iron bacteria (*Leptothrix*) showing ferric hydroxide particles attached to rod-shaped filaments. All magnifications 300 ×.

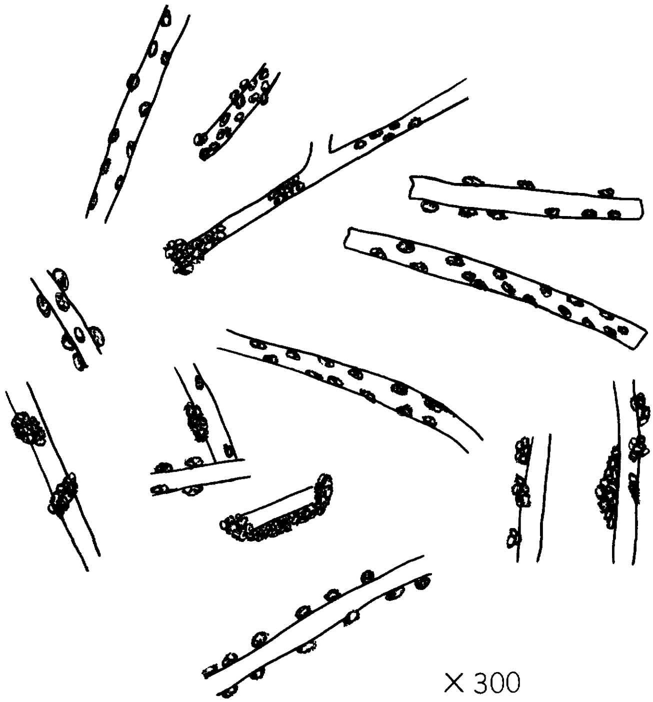

FIGURE 20.—Cross sections of leaves of water-submersed soil-rooted plants. Chlorophyll-bearing parts represented by shading. *A*, Horned or sago pondweed; *B*, Waterweeds or redhead pondweed; *C*, Water stargrass and cattails.

Table 5 was prepared by averaging data in table 4 based on plant-type and plant-part groupings. In summaries *A* and *B* of table 5, percentage of dry matter was higher and percentage of ash in the dry matter was lower in the whole land plants than in the leaf or comparable culm plant part. For the other three plant types in summary *A*, percentage of dry matter was lower and percentage of ash in the dry matter was higher in the whole plant than in leaf or comparable culm plant parts. Iron content of the whole plant was much higher than the iron content of leaf and culm parts.

Summaries *C* and *D* of table 5 show that for water plants, the percent of dry matter in both the emergent and submersed whole plant was about half the percent of dry matter in leaf, or comparable culm plant parts. The ash was 50 to 100 percent and iron contents 13 to 25 times higher in the whole plant than in the leaf or culm only. Leaves of water-submersed plants had 2 to 3 times more iron than did comparable parts of water-emergent plants.

Summary *D* of table 5 indicates that water-submersed plants had five times as much iron per unit weight of dry matter as water-emergent plants.

Summary *E* of table 5 indicates that the percentage of dry matter in water plants is about 65 percent that of land plants, and dry matter of land plants is about one-third that of rock plants. Although the proportion of ash in the dry matter is nearly the same for rock and water types, both are about 50 percent higher than for land type. The iron content of the dry material is about the same in the rock plants as in the water plants. The dry matter of these 2 types of plants contain 17 times more iron and, therefore, have higher percentages of iron than do land plants.

The correlation between amount of chlorophyll-bearing tissue and iron content is obscured somewhat in the results of the plant analyses in tables 4 and 5 because much of the iron in the plants is in the metabolically active roots rather than in the green parts above ground. However, results do show that the percentage of iron in ash of leaf material is about 2 times as high for water-submersed plants as it is for other plants. This high iron percentage probably is associated with chlorophyll concentration in the leaves of water-submersed plants. (See fig. 20.)

CONCLUSIONS

This study has shown that water plants, and apparently rock plants also, easily remove iron and presumably other mineral salts from the substrata in which they are rooted or from the water medium in which they are immersed.

Living iron-rich plants assimilate iron, other mineral salts, water, and carbon dioxide into matter that may be used as food or as part of the plant body. At death, catabolic processes cause the mineral salts, including iron, to be released to the water possibly as organic complexes. Organic debris resulting from dead plant material can help reduce iron in soil or mud in the bottoms of lakes to the ferrous form, which is readily soluble. Aquatic plants may, therefore, be important in bringing iron into solution in water.

In two different growth situations—with smaller duckweed (*Lemna minor* L.) and with saltcedar (*Tamarix gallica* L.)—plants having less than optimum quantities of iron available were a pale or light green. With duckweed, oxygenation of the surface water that is the exclusive source of nutrients for the plant apparently kept dissolved iron content low; and with saltcedar, the deep green and dull green could be correlated with the iron content of the soil.

Although the soil surrounding the Federal Center lake contains enough iron for plant growth, the lake-bottom muck, containing abundant organic matter, probably is more favorable than the surrounding soil for releasing iron to plant roots.

Roots, particularly those of soil-rooted aquatic plants, store much iron. Regions of high metabolic activity, like roots and buds, seem to be particularly rich in iron. The iron content of a whole plant may thus be 10 to 25 times greater than would be indicated by analyses of leaves alone.

Analyses of the whole plants show that the submersed aquatic types have more than three times as much iron per unit of plant ash as the emergent aquatic species. Soil-rooted aquatic species in general have 3 to 7 times more iron per unit of ash than the water-rooted species.

Lichens help release iron and other rock minerals for solution. Iron content of lichens is of about the same magnitude as that in water plants when based on ash or dry matter. In the alga-fungus association in lichens, the fungus seems to provide the water, which it absorbs from substratum or from fog and moist air, and to prevent desiccation of the alga during low humidity. The fungus also helps provide proteins and mineral salts, including iron. The alga provides carbohydrates and other foods. Lichen roots, better known as rhizoids, may penetrate rocks for several millimeters. They help corrode and decompose the rock supplementing the other forces of weathering, and by mixing the rock particles with their own remains build up soil containing iron available for growth of other vegetation.

The experimental results obtained in this study give some idea of the amounts of iron contained in different types of plants and in different plant parts, and they help to emphasize the potential importance of plants as sources of iron in natural water or as factors in the removal of iron from solution.

REFERENCES CITED

American Society for Testing Materials Standards, 1957, Standards on cement (with related information) : Am. Soc. Testing Materials Rept. E11-39, 264 p.

Birge, E. A., and Juday, C., 1926, Organic content of lake water: Bur. Fisheries Bull., v. 42, doc. 1012, p. 185-205.

Bonner, J. F., 1950, Plant biochemistry: 1st ed., New York, Academic Press, 537 p.

Boston Flower Market and New England Florist, 1896, The Boston fern.—*Nephrolepsis exaltata* var. *Bostoniensis*: Boston Flower Market and New England Florist, v. 2, p. 134.

Bowes, A. D., and Church, C. F., 1952, Food values of portions commonly used: 7th ed., Philadelphia, Coll. Offset Press, 94 p.

Butcher, R. W., 1933, Studies on the ecology of rivers, part 1—On the distribution of macrophytic vegetation in the rivers of Britain: Jour. Ecology, v. 21, p. 58-91.

Correns, C. W., 1941, Geochemistry of manganese and iron: Akad. Wiss. Göttingen Nachr., Math.-Phys. Kl., no. 5, p. 219-230.

Davenport, G. E., 1896, *Bostoniensis*: Boston Flower Market and New England Florist, v. 2, p. 150.

DeGruchy, J. H. B., 1938, A preliminary study of the larger aquatic plants of Oklahoma with special reference to their value in fish culture: Oklahoma Agr. Mech. Coll., Agr. Expt. Sta., Stillwater, Okla., Tech. Bull. 4.

Eaton, F. M., 1954, Formulas for estimating leaching and gypsum requirements of irrigation waters: Texas Agr. Expt. Sta., misc. pub. 111, 18 p.

Ellis, David, 1919, Iron bacteria: London, Methuen and Co., 179 p.

Escudero, A., Herraiz, M. L., and Senra, R., 1944, Study of the nutritive value of cress: Assoc. Argentina Dietologia Rev. 2, 5, p. 54–56.

Fernald, M. L., 1950, Gray's manual of botany: 8th ed., New York, Am. Book Co., 1632 p.

Gortner, R. A., 1934, Lake vegetation as a possible source of forage: Science, v. 80, p. 531–533.

Harper, H. J., and Daniel, H. A., 1934, Chemical composition of certain aquatic plants: Bot. Gaz., v. 96, p. 186–189.

Harvey, H. W., 1939, Substances controlling the growth of a diatom: Marine Biol. Assoc. Jour., United Kingdom, v. 23, p. 499–520.

Hayward, H. E., and Magistad, O. C., 1946, The salt problem in irrigation agriculture: U.S. Dept. Agriculture, misc. pub. no. 607, p. 23.

Hem, J. D., 1960, Complexes of ferrous iron with tannic acid: U.S. Geol. Survey Water-Supply Paper 1459–D, p. 75–94.

Keller, W. D., 1955, The principles of chemical weathering: Columbia, Mo., Lucas Bros., 88 p.

Lepper, H. A., Chm., 1950, Official methods of analysis of the A. O. A. C.: Washington, D.C., Assoc. Official Agr. Chemists, 910 p.

McLester, J. S., 1946, Nutrition and diet in health and disease: 4th ed., Philadelphia, W. B. Saunders Co., 849 p.

Meyer, B. S., and Anderson, D. B., 1948, Plant physiology: New York, D. van Nostrand Co., 696 p.

Miller, E. C., 1938, Plant physiology: New York, McGraw Hill Book Co., 776 p.

Nierenstein, M., 1945, Tannin content of the *Potamogeton* species and its effect on the color of iron-containing inland waters: Analyst, v. 70, p. 427.

Oborn, E. T., 1960, A survey of pertinent biochemical literature: U.S. Geol. Survey Water-Supply Paper 1459–F, p. 111–190.

Oborn, E. T., Moran, W. T., Greene, K. T., and Bartley, T. R., 1954, Weed control investigations on some important aquatic plants which impede flow of western irrigation waters: U.S. Bur. Reclamation, Joint Lab., Rept. no. SI–2, 84 p.

Pond, R. H., 1903, The biological relation of aquatic plants to the substratum: U.S. Commissioners Fish and Fisheries Rept., v. 117, p. 483–526.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

Read, B. E., and Gow, G. K., 1927, Iodine, arsenic, iron, calcium, and sulfur content of Chinese medicinal algae: Chinese Jour. Physiology, v. 1, p. 99–108.

Robinson, T. W., 1958, Phreatophytes: U.S. Geol. Survey Water-Supply Paper 1423, 84 p.

Rummeni, G., 1955, Model studies of the physiological oxidation-reduction potential of plants and the chemism of its regulation: Friedrich-Schiller-Univ. Jena Wiss. Zeitschr., Math.-naturw. Reihe, p. 611–632.

Schatz, V., Schatz, A., Trelawny, G. S., and Barth, K., 1956, Significance of lichens as pedogenic (soil-forming) agents: Pennsylvania Acad. Sci. Proc., v. 30, p. 62–69.

Shapiro, Joseph, 1958, Yellow acid-cation complexes in lake water: Science, v. 127, p. 702–704.

Smith, G. M., 1950, Fresh-water algae of the United States: 2d ed., New York, McGraw-Hill Book Co., 719 p.

Spector, W. S., 1956, Handbook of biological data: Philadelphia, W. B. Saunders Co., 584 p.

Tanaka, Motoharu, 1953, Chemical study of the mineral metabolism of lakes: Nagoya Univ., Jour. Earth Sci., v. 1, p. 119–134.

West, E. S., and Todd, W. R., 1955, Textbook of biochemistry: 2d ed., New York, MacMillan Co., 1356 p.

Woodman, A. G., 1941, Food analysis: New York, McGraw-Hill Book Co., 607 p.

Yust, Walter, 1951, Soil microbiology: Chicago, Ill., Encyclopedia Britannica, v. 20, p. 933.

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