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1-10-40

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DIVISION OF FISHERIES
MICHIGAN DEPARTMENT OF CONSERVATION
COOPERATING WITH THE
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December 12, 1939

REPORT NO. 568

PRELIMINARY REPORT OF WATER SOILS INVESTIGATION

by

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The interrelation of the causal influences affecting the biological productivity of our inland waters has been a troublesome question for many years in both the Old World and the New. One of the more recent problems which has arisen in this connection is the study of watersoil fertility. In the last decade considerable work has been done in the fertilization of artificial ponds in Europe as well as in the United States. Findings up to date seem to indicate that commercial fertilizers properly applied to these ponds result in tremendous increases in fish production. The question then arises as to whether or not a similar increase could be expected by fertilization of our natural waters.

Since the lakes of our state are attracting an increasingly larger number of sportsmen each year, we may reach a point where the natural productivity of the lakes can no longer provide an adequate fish supply. Artificial propagation and planting of fish in our lakes and streams was the first solution attempted. This has proved rather expensive and does not seem to be an entirely satisfactory answer to the problem. It is believed that, in general, natural reproduction will occur as rapidly as the environmental conditions will allow so that improving food and spawning conditions may be a more satisfactory means to increase the actual yield of fishes.

The importance of aquatic flowering plants as a factor in determining the fish population of our waters has long been realized. Watersoils, however, have received relatively little attention due to the controversy among plant physiologists as to whether or not the plant nutrients are obtained by the plant root from the soil. A brief summary of the outstanding work in this field may aid in establishing a background for the work being done at present.

H. R. Pond, in "Biological Relation of Aquatic Plants to the Substratum," U. S. Commission of Fish and Fisheries, Doc. 566, 1905, describes some experiments by which he attempted to demonstrate the relation of aquatic plants to the substratum and the function of the roots of some of the aquatics. In his experiments he used _Vallisneria, Elodea, Myriophyllum, P. obtusifolius, P. perfoliatus,_ and _Ranunculus aquatilis._ He grew each of these plants under the following conditions, (1) rooted in soil, (2) rooted in washed sand, (3) anchored over soil, and (4) anchored over washed sand. He found that the plants did much better when rooted in the substratum than when anchored over the substratum. The plants were grown under controlled conditions in aquaria. He also worked with nutrient solutions but had little success. From his results he concludes that these plants are "dependent upon their rooting in the soil for optimum growth and that they cannot survive a single season if denied a substratum of soil," and further that "the primary cause of the retarded growth of anchored plants is their inability to secure enough phosphorus and potassium, and possibly other elements."

K. Snell, in "Untersuchungen uber die Nahrungsaufnahme der Wasserpflanzen," Flora 98: 213-349, 1908, describes experiments which he conducted in an attempt to solve the same problem. He repeated Pond's work--using only Elodea. He placed 10 sprouts (without roots) of 10 cm. each in the aquaria. During the experiment all of the plants developed roots. His results differed from Pond's in that he found that the plants anchored over soil grew better than those rooted in sand. Measuring total combined lengths of the 10 plants in each treatment, his results are: (1) rooted in soil - 308.0 cm., (2) rooted in washed sand - 114.0 cm., (3) anchored over soil - 177.5 cm., and (4) anchored over washed sand - 114.0 cm. He also noted that only the roots developing in a substratum showed root hairs.

Then W. H. Brown, publishing his work entitled "The Relation of the Substratum to the Growth of Elodea" in the Philippine Journal of Science, C. Bot. 8: 1-20, repeated Pond's work and obtained similar results. But he completely eliminated the difference in growth between the rooted plants and those anchored by passing free carbon dioxide through the water several times a day, and hence concluded that "the non-rooted plants do not suffer from a lack of nutrient salts, but chiefly from a lack of the supply of carbon dioxide given off by processes of decomposition in the soil." He believes that by being rooted, the plants are held closer to the supply of CO_2 and can utilize it before it is taken out of solution by algae, etc.

Finally, in 1932, W. S. Bourn published "Ecological and Physiological Studies on Certain Aquatic Angiosperms" in Vol. 4 of Boyce Thompson Institute for Plant Research Contributions, pp. 425-496. This is probably the best and most comprehensive work done in this field up to date. He used Naias flexilus, P. perfoliatus, and P. foliosus. By using soil, washed sand, and no substratum, by using both nutrient solutions and tap water, and by adding CO_2 in order to maintain various concentrations of this gas and adding none whatsoever, he produced a tremendous variety of conditions and secured a prodigious quantity of data. His results differ appreciably from those previously reported by Brown, and are not in entire agreement with Pond. He shows that rooted plants grow better than the non-rooted plants, that the addition of nutrients by nutrient solutions increases growth, that keeping the CO_2 concentrations above that produced by decomposition increases growth, but "while a deficiency of CO_2 is found to be an important factor limiting the growth of aquatic plants, -- a constant supply of CO_2 does not eliminate the difference between plants rooted in soil and those merely anchored in solutions."

We see, then, that it is quite generally agreed that a rooted condition is advantageous to plant growth. Also, Bourn's work indicates that addition of nutrients increases plant growth, as well as does the addition of CO_2. Hence, might it not be possible to add nutrients in the form of commercial fertilizers and to add a potential supply of CO_2 in the form of organic matter when and if deficiencies of these materials occur?

It is in an attempt to answer the above questions that this work has been initiated. Rapid chemical tests were applied to soils from various lakes throughout the state in an attempt to determine the amounts of certain plant$ nutrients available in various watersoils. Several aquatic plants were ashed and analyzed for phosphorus. This particular element was selected because it is an element which often occurs in insufficient quantities in agricultural soils. The relative value of the various plant nutrients for aquatic plants, however, has not been definitely determined and it is possible that a phosphorus deficiency in watersoils would not bear the same relation to the aquatic plant as does a phosphorus deficiency in an agricultural to the average farm crop.

Fertilizer applications were made in pot tests in the greenhouse in order to obtain some idea as to the effect of the addition of commercial fertilizers to watersoils. Following these some similar tests were initiated in test plots at Rose Lake. The Neubauer Test--a standard test for the determination of fertility of agricultural soils--was applied to soils from the bottoms of five lakes in the vicinity of Ann Arbor. This test was applied for the purpose of determining the practicability and adaptability of the test to watersoils as well as the fertility of the particular samples at hand. The various phases of the work thus far will be discussed individually and treated in much more detail later.

Methods for obtaining soil samples varied from time to time as the work progressed--depending largely upon the size of the sample required for the particular purpose for which the soil was to be used. For the Neubauer work the samples were secured with the Ekman dredge. The soil used in the pot tests was from Rose Lake and consisted of an organic slime. It was dipped up with a 12 quart bucket and brought into the laboratory in 10 gallon milk cans. For use in the rapid chemical tests, a relatively small sample is required so the Davis Peat sampler was found quite satisfactory. Since this instrument has not been generally used in lake work and is not as well known as most of the standard samplers such as the Ekman and Peterson dredges, it will be briefly described.

The Davis Peat sampler consists of a cylinder containing a plunger and is supplied with a series of metal rods each two feet long. Each rod has an outside thread on the lower end and has a coupling fastened to the upper end so that when attached end to end, a long relatively rigid rod results. The rod at the lower end is attached to the plunger of the sampler. The cylinder is 3/4 inch in diameter and 8 inches long. (The sample delivered by the standard sampler was rather small so another cylinder and plunger with the diameter twice that of the original (3/4 inch) was made and the amount obtained with it was of suitable size.) The plunger fits snugly so that when the sampler is lowered with the plunger in position no material is allowed to enter the cylinder. When the sampler has reached the desired depth the plunger is pulled up until it automatically catches. This can be felt as a slight jar in the rods. The instrument is then forced downward about 8 inches, securing a sample of the soil or bottom at a known depth. The instrument is pulled up, the automatic catch released, and by pushing the plunger the soil sample is forced out.

This instrument is found to be very satisfactory under most conditions. It becomes difficult to operate when the water reaches depths of over 18 to 20 feet since at those depths the rods are not rigid enough to withstand the force necessary to insert the sampler into the bottom. The sampler is also limited to the softer bottoms. When used in sand, small particles find their way between the plunger and the cylinder. These sand particles impair the operation of the plunger and are rather difficult to remove. Soils whose consistency is more or less semi-fluid due to the suspended condition of the bottom material are often too thin and consequently run out of the cylinder as the instrument is lifted. Sandy soils can usually be secured by wading and be brought up with a dipper.

The chief advantage which the Davis Peat sampler holds over the Ekman dredge is its ability to secure more than the first few inches of the surface material. In some cases marl was found beneath a 16-20 inch layer of coarse undecomposed vegetable debris. In these cases it is quite possible that the Ekman dredge would have taken only the coarse material while the underlying soil was more largely responsible for the vegetative growth present, the evidence of which is the fact that the plants were found to be rooted in the marl.

The operations in the field were carried out in boats. The littoral zone was examined and collecting stations located wherever large weed-beds occurred. Soil samples were taken with the Davis Peat sampler. Whether or not the bottom deposits showed stratification was first determined. If no stratification was evident, the samples were taken at random from the upper 2 or 3 feet. When stratification occurred, the depths of the various strata were noted and samples of each stratum taken. Samples were placed in pint jars and properly labeled.

A list was made of the vegetation at each station and of plant specimens which could not be identified in the field were collected. The amount of wave action which each station might suffer was expressed rather arbitrarily but conclusions were based on the distance of the surface exposed to the prevailing winds, shore features, protection from wind, etc. The depth of the water was recorded at each station. Turbidity was expressed arbitrarily and based chiefly upon the depth at which the bottom was visible. It is fully realized that an error is introduced here since the color of the bottom determines to some extent the depth at which it is visible. A Secchi disk was not included in the list of equipment. However, most of the depths encountered were not of sufficient magnitude to permit the use of this instrument. Hardness of the water was determined by means of a standard soap solution and is expressed as grains per U. S. gallon. The soap solution was checked with a standard periodically. Surface temperature and pH were taken at each station. The pH was determined with a Soiltex outfit--a colorimetric test designed by the Soils Department at Michigan State College. The color chart gives readings at intervals of .5 and has a range of pH from 3 to 9, which would doubtless include all of the natural waters of the state. The pH could therefore be estimated to .25. It is felt that these readings are sufficiently accurate for the purpose intended.

A large quantity of data has accumulated from the result of this study and will be summarized in tabular form. The soil samples have been divided into five dominant types--each being treated separately. A brief description of the types as used here is as follows:

1. Sand. Soils included under this type are those whose outstanding characteristics are due to the sand content. Unless otherwise indicated, a clean, compact, light-colored sand will be implied when the term is used. Sand may be found in conjunction with marl, peat, shells, or very finely divided particles of organic matter. It should be realized that innumerable combinations of the various components may and do occur in nature. As mentioned above, however, as long as the characteristics due to the sand are dominant, the soil will be included under this heading--the modifications when present will be given in a column provided for that purpose.

2. Clay. This term is used to designate those soils which are composed of extremely finely divided particles of inorganic material. As such, clay is generally found in the lower strata of the bottom deposits and in relatively pure form.

3. Slime. Watersoils included under this heading are characterized by a dark color, a semi-suspended condition of the components, and offering only a limited resistance to passage of heavier objects such as sounding leads, etc. Here again, there are many possible intergrades between slime and the firmer deposits included under peat. Inclusions of all sorts may occur in slime. Some of the more common ones are marl, shells, sand, and clay. All degrees of decomposition of the plant constituents found in the slime also occur, giving a rather variable texture.

4. Peat. Included under this type are those soils which, like slime, are composed of plant remains. Unlike slime, however, peat deposits are more firm and when secured with the Davis sampler a relatively firm core is received. This soil varies with the nature of the original plant material, environmental conditions under which decomposition has occurred, and the degree of composition. Three distinct divisions are recognized: (a) fibrous--including all those whose composition is largely remains of herbaceous plants, (b) woody--composed chiefly of woody material, and (c) gelatinous sedimentary--peat characterized by a green color, homogeneity, and a rather firm but gelatinous consistency. Again inclusions may involve marl, shells, clay, etc.

5. Marl. This type includes those watersoils whose dominating characteristics are due to the marl content. Inclusions or modifications are listed in a column describing the particular deposit under consideration.

The first series of tables gives the results of the rapid chemical tests. These tests were made with the Spurway Testing outfit. These tests were designed to give a rather rapid test for the available plant nutrients in agricultural soils, but it is believed that they are applicable without modification to the air-dry watersoils. Tests for the following nutrients are possible with the Spurway Test: NO_3, NO_2, NH_4, Al, Mg, Mn, P, K, Ca, CO_3, Fe, SO_4, and Cl. The following tables give the amounts of some of the more important nutrients in the five dominant watersoil types. The figures in the table directly below the nutritive substance give~~s~~ the range in parts per million which can be obtained directly by the Spurway Test. Readings greater than these are obtained by dilution. Hardness of the water is approximate and is expressed as grains per U. S. gallon.

SAND

Sample Number	Modifications or Inclusions	Water Hard	pH	NO_3 0 - 25	P 0 - 10	K 0 - 20	Ca 0 - 200	Mg 0 - 7	Fe 0 - 50
2	Much dark organic matter	14	7.5	tr.	...	...	100	...	tr.
7	Abundance of shells	13	9.0	4	tr.	2	200	7	tr.
15		13	7.5	6	tr.	...	100	6	...
27		12	7.8	5	...	...	200	6	10
44		11	7.5	tr.	...	tr.	200	8	...
45		11	6.3	tr.	0.75	...	...	5	...
60	Much organic matter		8.0	...	...	...	150	24	...
61	Varying from dark gray to black, organic matter		7.0	20	tr.	...	125	8	...
63	Considerable organic matter		8.0	...	...	...	175	16	...
64	Dark color	12	7.5	...	0.5	...	175	8	...
65	Brown in color	12	7.2	...	0.5	...	...	4	...
67	Marl mixed in	12	7.0	...	0.5	...	...	1	...
68	Black, compact	8	5.5	...	tr.	20	...	6	...
70		8	5.5	...	...	...	...	4	...
71		13	7.5	...	...	...	...	1	...
72		11	5.0	8	tr.	...	100	7	...

MARL

Sample Number	Modifications or Inclusions	Water Hard	pH	NO_3 0 - 25	P 0 - 10	K 0 - 20	Ca 0 - 200	Mg 0 - 7	Fe 0 - 50
3	Impure	14	9.0	7	tr.	...	160	...	...
4	Composed chiefly of very small shells	14	8.0	10	...	...	200+	...	...
8		13	8.5	20	...	...	200+	7	...
18		13	8.5	...	...	...	200+	8	...
19	Impure, much organic matter	13	8.0	25	...	...	200+	24	...
21			8.0	1	...	...	200+	16	...
22	Considerable organic matter		7.8	3	...	...	200+	6	...
24	Numerous plant fibers		8.0	3	...	...	200+	8	...
26			8.0	5	...	tr.	200+	8	...
28		12	8.2	5	...	...	200+	4	...
40	Impure	18	7.8	4	...	...	200+	24	...
43	Sedimentary peat mixed in	9	8.5	7	...	...	200+	8	...
46	Impure	11	8.5	2	...	...	200+	8	...
49		11	8.2	5	...	...	200+	8	...
51		11	8.5	40	...	...	200+	8	...

PEAT

Sample Number	Modifications or Inclusions	Water Hard	pH	NO_3 0 - 25	P 0 - 10	K 0 - 20	Ca 0 - 200	Mg 0 - 7	Fe 0 - 50
11.5	Green gelatinous	13	7.0	5	tr.	...	125	3	...
20	Prolific Chara growth pH of water - 8.5	13	5.5	25	0.5	...	125	14	...
23	Sedimentary containing many small shells		8.0	8	1.5	...	200+	8	...
41	Numerous shells	18	7.6	4	...	...	200+	24	tr.
47	Gelatinous	11	7.0	8	0.5	...	125	16	...
50	Gelatinous	11	6.0	40	0.5	...	125	8	...
52	Gelatinous	5	5.0	10	...	...	...	8	...
53		5	5.0	5	...	...	...	8	...
66		12	6.5	7	tr.	...	150	20	...
69		8	6.5	...	0.75	...	150	10	...
100	Marl under shore but not under bottom	16	8.0	...	...	...	200	24	...
101	Gelatinous	16	7.7	...	...	...	125	7	...
107		8	5.5	25	...	2.5	125	14	...
130	Contains marl	8	8.5	5	...	...	200+	7	...

SLIME

Sample Number	Modifications or Inclusions	Water Hard	pH	NO_3 0 - 25	P 0 - 10	K 0 - 20	Ca 0 - 200	Mg 0 - 7	Fe 0 - 50
1		14	8.0	5	tr.	...	130	...	...
6		14	7.5	4	tr.	2.0	175	6	tr.
11	Clayey material mixed	13	8.5	5	tr.	...	200	40	tr.
12	Marl and shells	13	8.5	10	tr.	...	200	24	...
14		13	7.0	5	tr.	...	125	10	tr.
17	Marl at depth of 2 ft.	13	7.5	...	...	...	200	15	...
25	Marl underneath		7.8	8	tr.	5.0	200	10	tr.
48	Green color, shells included	11	7.8	5	...	...	150	8	...
54	Green color, very thin	5	5.5	...	...	...	...	8	...
102	Some marl mixed	14	8.0	...	1.5	...	200	7	...

CLAY

Sample Number	Modifications or Inclusions	Water Hard	pH	NO_3 0 - 25	P 0 - 10	K 0 - 20	Ca 0 - 200	Mg 0 - 7	Fe 0 - 50
5		14	8.0	2	tr.	tr.	200	7	tr.
9		13	8.2	15	...	...	200	35	...
10		13	9.0	2	tr.	...	200	40	...
13		13	7.5	8	tr.	...	200	24	tr.
16		13	7.5	7	...	...	200	10	...

The table below shows the frequency with which some of the more common aquatic plants occurred on the various types of watersoil. The figures represent the percentage (based on the total number of observations) occurrence on the particular soil type heading the column.

Plant	Sand	Marl	Slime	Peat
Ceratophyllum	25	13	13	31
Potamogeton amplifolius		42	29	29
Myriophyllum	19	19	31	31
Chara	33	15	19	33
Nymphozanthus	20		40	40
Pontederia	38	10	18	36
Nymphaea	20	12	34	34
Potamogeton compressus	13		37	50
Naias	25		50	25
Potamogeton pectinatus	17		33	50
Elodea		13	37	50
Potamogeton natans	40	40		20
	70	30		
Vallisneria	25		75	

Plants which were not observed frequently enough to warrant their inclusion in the above table are: Brasenia, Sagittaria, Heteranthera, Peltandra, Utricularia, Polygonum, Potamogeton praelongus, P. gramineus, and Eriocaulon.

An analysis of the figures presented in the above table seems to indicate that most plants will grow on a variety of soil types. Slime and peat seem to be more universally suitable substrata than do sand and marl. In this connection it should be mentioned that in the data thus far, only one or two of the very acid, soft-water lakes have been observed. Some plants show distinct preferences for the organic soils while others show preference for the inorganic soils.

Ash Analysis of Aquatic Plants

During the latter part of the summer, plant samples were collected for the purpose of determining a possible relationship between the content of a nutritive element (phosphorus) in the plants and that of the soil in which they grew. Phosphorous was selected because deficiencies of the element probably occur more frequently in agricultural soils than do those of other elements. In relation to watersoils, H. R. Pond, in "Biological Relation of Aquatic Plants to the Substratum," U. S. Commission of Fish and Fisheries, Doc. 566, 1905, comes to the conclusion that "the primary cause of the retarded growth of anchored plants is their inability to secure enough phosphorus and potassium, and possibly other elements."

The table on the next page gives the results of the analyses of a number of aquatic plants as well as the phosphorus content of the watersoils as determined by the Spurway Tests. An examination of this table indicates:

1. There is a rather wide variation in the phosphorus content of aquatic plants.

2. Different species of plants growing on the same soil absorb different amounts of phosphorus.

3. A single species of plant does not contain a uniform phosphorus content but varies tremendously with environmental conditions.

4. Aquatic plants must have tremendous extracting powers since the Spurway tests are able to detect available phosphorus in concentrations of less than 0.5 ppm. and in many cases the soils and water show zero readings.

5. There seems to be no correlation between the amounts of phosphorus in the substratum and in the plant--even within the same plant species.

Comparison of Phosphorous Content of Aquatic Plants

and That of Associated Soils as Determined by Spurway Test

No.	Plant(s)	Lake	Soil	Spurway Test (ppm) P	% P_2O_5 in Plants
P-1	Brasenia	Pine L. Barry Co.	Fibrous peat (7') gray marly peat (13')	0.0 0.0	.508
P-2	Naias	Pine L. Barry Co.	Fibrous peat (7') gray marly peat (13')	0.0 0.0	.351
P-3	P. pectinatus	Craig L. Barry Co.	Firm brown fibrous peat (6-8'), marl (?)	0.5	.256
P-4	Chara	Craig L. Barry Co.	Brown fibrous peat No sample taken		.227
P-5	P. amplifolius	Fish L. Oakland Co.	Green sedimentary peat (3'), brown fibrous peat	0.0	.534
P-6	Brasenia	Fish L. Oakland Co.	Ooze too thin to get with sampler		.359
P-7	P. compressus, Chara, P. sp.	Square L. Oakland Co.	Soft gray sedimentary peat and marl (8')	0.0	.452
P-8	P. sp.	Pleasant L. Oakland Co.	Green organic ooze and shells (2'), marl (2'), *sedimentary peat (6-8"), marl (1'), sand and gravel	0.0 *0.5 0.0	.441
P-9	P. sp.	Pleasant L. Oakland Co.	Sand	0.75	.283
P-10	Myriophyllum, Chara, green algae	Pond on U.S. 10 3 mi. N.W. of Clarkston	Sand and clay	0.0	.762
P-11	Lemna, Spirodela	Mona L. Muskegon Co.	Brown fibrous peat (6"), sand	tr.	1.098
P-12	Chara	Pigeon L. Ottawa Co.	Thin slime and fine fibrous peat (20')	0.75	.757
P-13	Heteranthera	Cook L. Livingston Co.	Brown fibrous peat (8') Green sedimentary peat (4'), sand and fine gravel	0.0	.833
P-14	Chara	Bennett L. Livingston Co.	Black fine organic slime (8"), sand and gravel	1.5	.296

It is realized that the amount of data does not justify final conclusions so those presented above are tentative until further studies are made.

It is also interesting to note that the highest phosphorus content occurrend in floating plants (Lemna and Spirodela) and in water showing only a trace of phosphorus.

Fertilizer Experiments in the Greenhouse

These experiments were designed to determine the effect of the addition of salts containing phosphorus and potassium to one type of watersoil. The soil used was taken from Rose Lake and is a slightly fibrous and quite well-decomposed peat. The tests on the soil showed no available phosphorus and a trace of available potassium. The experiments were carried out in 2-gallon earthen jars. The salts were thoroughly mixed in the soil (850 gms.) and then 250 gms. of acid-washed quartz sand were spread uniformly on the surface. Twenty-five wild rice seeds were planted in each jar. Tap water was added to within an inch of the top of the jar and kept at a constant level throughout the experiment. Similar tests were tried with Sago Pondweed tubers but the tubers failed to grow.

The tests were run in duplicate and over a period of 10 weeks. Treatments and results are given in the table below.

Pot No.	Treatment (per A.)	No. of Plants	Average Length (cm)	Fresh Wt. (gms)	Wt. of plants per treatment
1	500# primary Ca phosphate	12	34	14.2	33.9
2	" " " "	10	38	19.7	
3	2000# " " "	13	32	18.5	34.5
4	" " " "	10	43	16.0	
5	500# potassium chloride	7	52	25.5	38.4
6	" " "	15	32	12.9	
7	2000# " "	6	31	13.8	24.1
8	" " "	12	28	10.3	
9	Control	19	24.5	17.4	49.4
10	"	7	69	32.0	
11	500# primary Ca phosphate 1500# potassium chloride	6	29	6.6	42.6
12	500# primary Ca phosphate 1500# potassium chloride	8	59	36.0	

Due to the magnitude of the variation between the duplicates of individual treatments, the data lack significance. However, viewing the experiment from a non-statistical standpoint, a few conclusions may be ventured:

1. The application of 2000# of potassium chloride was too heavy since minimal growth occurred here and the plants presented a "burned-up" appearance. They were spindly, small, and discolored.

2. The addition of both salts gave the greatest growth. The number of plants here was small but the average weight per plant was 3.04 grams as compared with an average weight per plant in the control of 1.88 grams. It is possible that the application affected the young sprouts, thus reducing the number of plants.

Rose Lake Plots

Following the greenhouse pot tests, it was considered desirable to make some fertilizer applications on a larger scale and under more natural conditions. Experimental plots were constructed at Rose Lake under arrangements with the Game Division of the Michigan Conservation Department. These plots were constructed in the floating bog surrounding Rose Lake. The mat of vegetation here is about 18 inches thick and is underlain by varying depths of oozy fibrous material of the same nature as that comprising the bottom of Rose Lake. Excavations were made to a depth of 3 feet. Wood cribs were placed in the pools to prevent the oozy material from filling them in. Plots of two different sizes were made--3 of 15 feet square and 9 of 10 feet square. The plots were placed 25 feet apart.

Before adding fertilizers to the plots, it was necessary to know the rate and amount of diffusion of salts which would take place in order to be certain that the application of fertilizer to one pool would not affect the adjoining pools. An experiment was established in the bog to determine this. A series of holes 3 inches in diameter were bored through the surface mat at the following intervals from the hole in which the salt was to be placed: 1, 3, 5, 10, 15, and 25 feet. The salt (1500 gms. of KCl) was put in the end hole after a sample of the water and soil had been tested for potassium with the Spurway outfit and found to be very low--less than 5 parts per million. The following day the water in the holes was tested. The salt had not diffused to the first hole (1') but 50 ppm. of potassium were found in the water where the salt had been introduced. Three days later tests were repeated. The water in the first hole showed a slight increase while the others remained unchanged. Four days more showed the same results. After two weeks tests on the water gave no results but when samples of the soil were used, the test in the original hole gave 40 ppm. available phosphorus, the first hole--5 ppm., and the remaining showed no change throughout the experiment. This is in accordance with the findings of Dr. Pyttik of Czechoslovakia who has done some work in this connection.

Equivalent amounts of vegetation were introduced into each pool. Plants used were two species of Potamogeton and one of Utricularia.

The experiment is still in progress, but the findings up to date are included here. A map showing the location and position of the pools is also included.

Pool and Treatment Per Acre	Examination on July 16, 1939	Examination on August 5, 1939	Examination on August 30, 1939
1. 500# ammon. nitrate Original pH - 8.0	Utricularia growing. Potamogetons living but making little growth.	Utricularia scant but plants present have healthy green color. Potamogetons nearly gone--one discolored plant remaining.	Soil test: pH 8.0, NO_3^- - 0.0, NH_4 - trace. Only 1/4 covered with water. Few shoots of Utricularia, no Potamogetons, scattered small plants of white water lily growing in soft mud. Lilies have been naturally introduced.
2. 500# ammon. nitrate Orig. pH - 8.0	Little or no growth of Utricularia, pondweeds almost lacking.	Few very small scrubby stems of Utricularia, no pondweeds	Soil test: pH-8.0, NO_3^- - 0.0, NH_4 - trace. Pool 1/2 covered with water. Few shoots of Utricularia, no Potamogetons, scattered plants of white water lily.
3. Control Orig. pH 8.0	No apparent increase in vegetation	Few Potamogeton and Utricularia plants (original planting), not very healthy	Soil test: pH 8.0, NO_3^- - 0.0. NH_4 - trace, P. - 0.0, K. - trace, SO_4^- - 0.0. Pool 1/2 covered with water to depth of 8" to 1'. Original plants living where in water, P. epihydrus encroaching. Original plants not very healthy.
4. 500# 62% metaphosphate pH 8.0	Water shallow, original plants healthy, green algae very prolific.	Utricularia green and in blossom. Scattering plants of Potamogeton, few small water lilies and a few duckweeds.	Soil test: pH 8.0, P - 2.5 ppm. Pool all dry but one corner. Plants here have healthy green color--both Utricularia and Potamogetons. P. epihydrus abundant on soft mud, Duckweed common, few yellow water lilies.
5. 500# 62% metaphosphate. pH 8.0	Utricularia very prolific, excellent color and blossoming. Algae common.	Much Utricularia, many duckweeds, small white water lilies, algae abundant, Potamogetons rather sickly.	Soil test: pH 8.0, P - 2.5 ppm. Completely covered with water. Utricularia prolific, Lemna quite common, few yellow and white water lilies. All plants have a good green color.
6. 2000#-62% metaphosphate pH 8.0	Water level lowering. Tremendous growth of algae and Utricularia, Potamogetons living but making little growth.	Water on one side only. Potamogetons present, Utricularia very numerous. All plants are green and in good shape.	Soil test: pH 7.8 P 1.5 - 2.0 Pool 1/4 covered with water. Utricularia abundant, Lemna minor and Lemna trisulca common, few yellow water lilies and P. epihydrus growing on soft mud.
7. 500# flour of sulfur pH 9.0	Original plants present but are discolored and not growing.	Only few plants present, Utricularia and Potamogeton plants are discolored--being dark purple and coated with lime.	Water test: pH 8.5 P 0.0, SO_4^- - 200 ppm. K 0.0 Pool full of water to depth of 2'. Original plants in position but discolored--dark purple, and covered with algae and lime.

Pool and Treatment Per Acre	Examination on July 16, 1939	Examination on August 5, 1939	Examination on August 30, 1939
8. 500# metaphosphate 1500# muriate of potash. pH 9.0	Utricularia grown considerably, algae very prolific, Potamogetons in good condition.	Utricularia doing excellently, and in bloom. Potamogetons good, well-rooted. Few white water lilies, sedges, and cattail.	Soil test: pH 8.5 P 2.5 ppm. K 10 ppm. $CO_3^{=}$ - 150 ppm. Entire bottom covered with water. Utricularia prolific, Potamogetons growing. White water lily common, few yellow water lilies, cattails and sedges at border.
9. 500# muriate of potash. pH 8.0	No water. Original Potamogetons existing.	No water. Four groups of Potamogetons, few sedges.	Soil test: pH 8.0 P 0.0 K 7.5 ppm. Pool completely filled with soft mud--due to lowering of water level. P. epihydrus and Sagittaria common, few sedges.
10. 500# muriate of potash pH 8.0	Half covered with water. Original plants present but no apparent growth.	Utricularia in deeper parts of the pool, also Potamogetons. P.s have well-filled heads and good seeds.	Soil test: pH 8.0 P. 0.0 K 5.0 to 7.5 ppm. Pool nearly dry. No noticeable growth of Utricularia. P. epihydrus and Sagittaria common on soft mud.
11. Control pH 8.0	Nearly dry, plants living but making little if any growth	Water almost gone. Few plants of Sagittaria, and sedges. Small algal growth.	Soil test: pH 8.0 P 0.0 K trace Pool in same condition as No. 10
12. 2000# muriate of potash pH 8.0	Nearly dry. Few plants of P. epihydrus and Sagittaria.	Almost entirely dry. Sixteen plants of Sagittaria, Potamogetons growing on soft mud. Few stunted plants of white water lily.	Soil test: pH 7.8 P 0.0 K 10 ppm. Pool in same condition as Nos. 10 and 11, with addition of few white water lilies.

The applications shown in the table were made in the last week in May, 1939 using commercial fertilizers from the Soils Department of Michigan State ~~the Spurway test~~ College. Before additions were made the soil in the pools was tested with the Spurway testing outfit. All of the pools showed a pH of 8.0, with the exception of Nos. 7 and 8. No. 7 has a marl bottom rather than the soft mud found in the other plots and had a pH of 9.0. Plot No. 8 has a soft mud bottom but there are minute mollusk shells scattered throughout--giving a high carbonate content. All of the pools gave a trace of potassium, no phosphorus, nitrates, or sulfates. The experiment has been partially destroyed by the large decrease of the water level. However, it seems that certain of the results are reliable and similar results could be expected elsewhere under similar conditions:

1. As shown by the diffusion experiment phosphorus and potassium must be applied uniformly over any area to be fertilized since they are readily fixed by the soil and become slowly available. Hence, if the fertilizer were dumped in piles on the bottom, only a very localized influence would result.

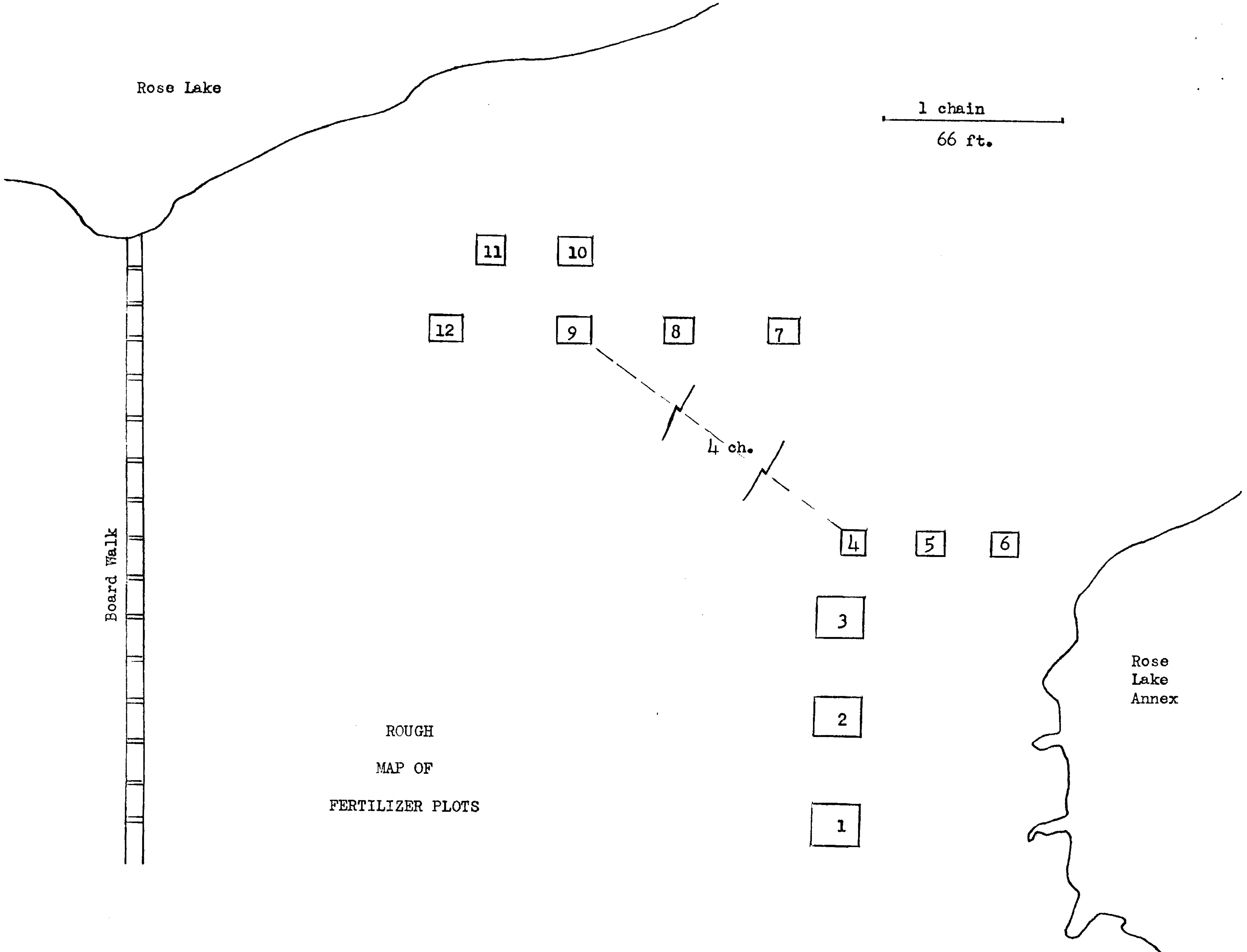
2. After a period of three months phosphorus and potassium are still readily available for plant use, although not in the same proportion as that in which they were added.

3. Nitrates added in the form of ammonium nitrate are soon lost and seem to have little, if any, effect on the higher vegetation.

4. The trace of potassium found naturally in this soil seems to suffice as far as the higher vegetation is concerned. Additions of potash had no noticeable effect.

5. The soil and water has a distinct phosphorus deficiency. In all cases additions of phosphorus have resulted in a rapid increase in vegetation. The algal response to applications of phosphorus is outstanding. It is probable that applications would be used rather rapidly by the algae and other phytoplankton, causing serious competition with higher aquatic vegetation for this nutritive element.

6. Applications of sulfur, at least using the amount applied in this experiment, do not have the beneficial effects that are obtained when applied to highly alkaline muck soils. The pH is lowered slightly but there is a pronounced discoloration of the vegetation. The effect of sulfur on animal life probably would be detrimental since there is a conspicuous lack of macroscopic fauna in this particular pool.


Rose Lake
1 chain
66 ft.
11
10
12
9
8
7
4 ch.
4
5
6
Board Walk
3
2
1
Rose
Lake
Annex
ROUGH
MAP OF
FERTILIZER PLOTS

Neubauer Tests

In studying the mineral or nutrient constituency of soils, it is also important to know and understand the availability of the elements as well as their existence in the soil. It is thought by some investigators that chemical tests do not give an accurate account of the availability since factors other than chemical factors may be involved in the determination of availability.

The Neubauer Method was devised in Germany and tested very critically both in Germany and the United States. It is now considered one of the better methods of determining fertilizer deficiencies and has been used as a research tool in studying fertilizer fixation and the influences of one nutrient on the absorption of another. In contrast to pot and field tests, it is comparatively rapid and inexpensive. This method is based on the determination of the amounts of nutrients extracted by a large number of plants from a relatively small sample of soil. Rye is the standard plant used, but since it was considered quite probable that aquatic plants might not have the same power of extraction as does rye, wild rice was also used in the test. It is assumed that the plants, due to the very strong feeding power in their early development, are able to exhaust the soil of its available plant food materials. It is desirable to have a supply of large uniform seeds. Rye was obtained from the Farm Crops Department at Michigan State College and the wild rice seeds were purchased from a commercial seed company.

Details of the procedure as given by S. F. Thornton in "Soil and Fertilizer Studies by Means of the Neubauer Method" are summarized as follows:

"Mix 100 grams of air-dried soil, which has been ground to pass a 2 mm. sieve, with 50 grams of nutrient-free quartz sand and spread uniformly over the bottom of a glass dish having a diameter of 11 cm. and a depth of 7 cm. Over this layer spread 250 grams of quartz sand. To facilitate watering, place a small glass tube in the center of the dish. In the surface of the sand layer carefully plant 100 selected and weighed rye seeds which have been treated with "Semesan Jr." dust disinfectant. Add 80 grams of distilled water and keep at a temperature of 20°C, avoiding exposure to direct sunlight. As a blank test, grow plants under similar conditions on quartz sand alone.

"At the end of the 17 day vegetation period, harvest the plants. By knocking on the sides of the dish, loosen the contents and remove as one piece. Place on a 2mm. sieve and wash away the majority of the sand and soil with a moderate stream of tap water. Separate the roots from the tops and free from the remaining sand and soil by means of repeated rinsings in a shallow dish. From the sieve gather all seed hulls, ungerminated seed and broken roots and place with the other plant material. Place in a suitable container such as a large crucible or small dish, dry and ash in an electric oven with an automatic temperature control at a temperature of 550°C.

"Moisten the ash with water, add 5-6 cc. of concentrated hydrochloric acid and evaporate on the steam bath to remove silica. Take up with a small amount of water and 2-3 cc. of concentrated hydrochloric acid, heat on the steam bath until solution is complete and transfer to a 100 cc. volumetric flask. Cool, fill to the mark and filter. Use this solution for determination of both phosphoric acid and potash.

"Phosphoric Acid. Transfer 20 cc. of the above solution to a 250 cc. beaker and proceed according to the volumetric method for the determination of phosphorus in fertilizers as given in the Official and Tentative

Methods of Analysis of the A.O.A.C.

"Potash. Transfer 40 cc. of the above solution to a 100 cc. volumetric flask, add 5 cc. of concentrated ammonium hydroxide and 5 cc. of a saturated solution of ammonium oxalate, heat to boiling on a hot plate, cool, make to volume, mix and filter. Using a 40 cc. aliquot of this solution, proceed as directed for the determination of potash in mixed fertilizers by the platinic chloride method in the Official and Tentative Methods of Analysis of the A.O.A.C."

Phosphorus and Potassium Content of
Plants Grown in Neubauer Tests

Soil	Lake	Plant	K_2O mgm.	P_2O_5 mgm.
Ck--1	(Quartz sand)	Rye	26.62	32.03
479-2	Baseline Lake	Rye	23.17	32.79
403-3	Bass Lake	Rye	31.39	29.96
435-4	Third Sister Lake	Rye	23.66	27.74
440-5	Ford Pond	Rye	32.97	35.43
477-6	Third Sister Lake	Rye	34.97	29.69
Ck--7	(Quartz sand)	Wild Rice	15.07	19.71
403-8	Bass Lake	Wild Rice	13.67	21.03
435-9	Third Sister Lake	Wild Rice	34.36	23.90
440-10	Ford Pond	Wild Rice	28.37	23.54

The following table gives a comparison between the results of the Neubauer test and those of the Spurway Test kit. The phosphorus and potassium content of the 100 gms. of soil used in each Neubauer jar is expressed in milligrams, while the readings from the Spurway test are in parts per million.

Soil	Phosphorus			Potassium		
	Spurway (ppm)	Neubauer (mgm)		Spurway (ppm)	Neubauer (mgm)	
	Soil	Rye	Wild Rice	Soil	Rye	Wild Rice
479	tr.	.76	No test	0.0	...	No test
403	0.0	...	1.32	0.0	4.77	...
435	0.75	...	4.19	10.0	...	19.29
440	1.0	3.40	3.83	2.5	6.35	13.30
477	0.25	...	No test	5.0	8.35	No test

From the data presented in the two preceding tables, it can be readily observed that the Neubauer Test shows a variation in the amount of phosphorus and potassium in the soils used in the experiment. The results do not correspond with the results of the Spurway Test. The Neubauer Test using rye gives results varying widely from that using wild rice. It is believed that the results obtained with the Neubauer method do not justify the time and labor required for its operation.

Summary and Conclusions

The work done thus far has been somewhat diversified in character in an attempt to determine a proper and suitable approach to the study of watersoil fertility and its bearing on fisheries work. Some definite conclusions have been reached but in many cases more work should be done to substantiate the tentative ones made here.

1. Watersoils in general are not as rich in plant nutrients as are agricultural soils.

2. As would be expected, there is considerable variation in the nutrient content of various soils.

3. Hydrosols or watersoils can be divided into five major types--each subject to considerable modification.

4. In marl there is a conspicuous lack of phosphorus, potassium and iron. These are three very important plant nutrients. This lack of nutrients indicates the possibility of a tie-up of plant nutrients in these lakes--accounting in part for the barrenness of many senescent marl lakes.

5. Highly alkaline soils from extremely alkaline hard-water lakes contain small amounts of plant nutrients. Highly acid soils from extremely acid soft-water lakes are also low or completely devoid of phosphorus, potassium, and iron as determined by the Spurway Test. It has been observed by many investigators that lakes of the above types are relatively unproductive from the standpoints of plankton population, vegetation, and larger invertebrates, including fish. Whether the lack of nutrients is the cause of this unproductiveness or is purely coincidental to it can only be determined by further study and experimentation.

6. Many plants can grow under a variety of conditions and on a variety of soil types. The density of the growth and the condition of the plants may vary, however, with different types of soil and under varying conditions, indicating that in spite of the wide range of tolerance of many plants, there probably exist optimum conditions.

7. Peat and slime (if not too acid) seem to be more universally suitable substrata than do sand and marl. These organic soils when having a pH below 6.0 are generally lacking in plant nutrients.

8. Some plants seem to show distinct preferences for organic soils while others commonly occur on harder inorganic soils.

9. Further studies should be made to determine to what extent the lack of nutrients in watersoils is responsible for the barren conditions in certain lakes and to determine the practicability and effectiveness of adding these nutrients.

10. There is a rather wide variation in the phosphorus content of aquatic plants.

11. The phosphorus content of the same species of plant varies under different conditions.

12. The phosphorus content of different plants growing on the same soil is not the same but varies widely.

13. The relation between the amount of phosphorus in the soil and that in the plant is not constant but varies considerably.

14. In pot tests differences between various tests were noticeable. The application of 2000 pounds per acre was apparently too heavy since growth was retarded and the plants were discolored. The combination of salts of both phosphorus and potassium yielded the greatest growth.

15. As shown by the diffusion experiment at Rose Lake, phosphorus and potassium should be applied uniformly over any area to be fertilized since these elements are readily fixed by the soil and become slowly available. Hence, if the fertilizer were dumped in piles on the bottom, only a localized effect would be realized.

16. After a period of three months phosphorus and potassium are still readly available for plant~~s~~ use, although not in the same proportion as that in which they were applied.

17. Nitrates added in the form of ammonium nitrate are soon lost and seem to have little, if any, effect on the higher vegetation. This applies to its addition to an alkaline slime soil.

18. The trace of potassium found naturally in the soil at Rose Lake seems to suffice as far as the higher vegetation is concerned. Additions of potash had no noticeable effect.

19. The soil and water at Rose Lake have a distinct phosphorus deficiency. In all cases additions of phosphorus have ~~xxxxitx~~ resulted in a rapid increase in vegetation. The algal response to applications of phosphorus

is outstanding. It is probable that applications would be used rather rapidly by the algae and other phytoplankton, causing serious competition with the larger aquatic plants for this nutritive element.

20. Applications of sulfur, at least using the amount applied in the Rose Lake experiment, do not have the beneficial effects that are obtained when applied to highly alkaline muck soils. The pH is lowered slightly but there is a pronounced discoloration of the vegetation. The effect of sulfur on animal life probably would be detrimental since there is a conspicuous lack of macroscopic fauna in this particular pool.

21. Further studies should include:

a. A continuation of the pools at Rose Lake and possibly construction of other test plots on different soil types.

b. Fertilization of small lakes or plots in a larger lake.

c. Collection of large samples of soil which seemingly should be supporting considerable vegetation but are entirely barren. Fertilizer applications should be made in jars and the effect on plant growth studied.

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