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TEMPERATURE EFFECTS ON THE SORPTION OF RADIONUCLIDES BY FRESHWATER ALGAE*

by

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ABSTRACT

Water temperatures of 23, 26, 29, and 32°C had no significant effect on the sorption of ^{137}Cs, ^{85}Sr, ^{65}Zn, ^{59}Fe, ^{57}Co, and ^{54}Mn by the filamentous green alga Stigeoclonium lubricum. Radionuclide concentrations in the unicellular diatom Navicula seminulum were 2 to 5 times higher at 32°C than those obtained at lower temperatures. Water temperatures of 25, 30, 35, and 40°C had no significant effect on the sorption of ^{137}Cs, ^{85}Sr, ^{65}Zn, and ^{59}Fe by the filamentous blue-green alga Plectonema boryanum. However, ^{57}Co concentrations in P. boryanum decreased with temperature, and ^{54}Mn concentrations increased from 25 to 35°C. Growth rates of N. seminulum and P. boryanum were inhibited at 32 and 25°C, respectively. Growth of S. lubricum was not influenced by the temperatures tested.

INTRODUCTION

The warm waters of the reactor effluent streams within the Savannah River Plant (SRP) area transport very low concentrations of fission and activation products through miles of natural streambeds and swamps to the Savannah River. These waters are sufficiently cooled to support abundant growths of blue-green, green, and brown (diatoms) algae prior to their confluence with the river. Studies are in progress at the Savannah River Laboratory to determine the role of these aquatic plants on the distribution, transfer, and fate of radioactive materials discharged into freshwater streams. The ability of these algae to concentrate radionuclides under near optimum growth conditions in the laboratory has been demonstrated by Harvey and Patrick (1967). Emphasis is now being placed on studying the effects of environmental factors on the sorption of radionuclides by representative species.

Diatoms generally grow best at water temperatures of 18 to 30°C, green algae at 25 to 35°C, and blue-green algae at 30 to 40°C (Cairns, 1956). Although the flora in a reactor effluent stream usually consists of species best suited for prevailing ecological conditions, the kinds of algae present overlap considerably because of wide differences in the thermal tolerance of species within an algal group. Laboratory studies (ORSANCO, 1956) have shown that a given alga may be affected by changes within its range of temperature tolerance: indirectly through changes in the physical and chemical characteristics of the environment, and directly by action on vital processes such as metabolic rate and growth. In this paper I report the direct effects of nonlethal changes in water temperature on the concentration of ^{137}Cs, ^{85}Sr, ^{65}Zn, ^{59}Fe, ^{57}Co, and ^{54}Mn by the unicellular diatom *Navicula seminulum* var. hustedii, and the filamentous green alga *Stigeoclonium lubricum*. Results are compared with data obtained in an earlier study (Harvey, 1969) with the filamentous blue-green alga *Plectonema boryanum*.

METHODS

The species studied were collected from the reactor effluent streams at SRP; unialgal cultures were developed in inorganic media (Table 1). Stock cultures of *N. seminulum* and *S. lubricum* were maintained in an actively dividing phase at 25°C; those of *P. boryanum* were maintained at 35°C. Uniform test inocula for both unicellular and filamentous species were prepared by blending concentrated stock solutions for 90 seconds, and then determining the volume of stock required to yield one milligram dry weight of algae.

All tests were conducted using the continuous flow culture system described by Watts and Harvey (1963). Algae inocula were placed on weighed filter membranes and attached with a slight vacuum to prevent the algae from being carried away by the current. Individual membranes were then placed in 125-ml sidearm filter flasks, and the appropriate medium containing 45 pCi each of ^{137}Cs, ^{85}Sr, ^{65}Zn, ^{59}Fe, ^{57}Co, and ^{54}Mn per ml was pumped through each flask at

15 ml/hr. *N. seminulum* and *S. lubricum* were grown in waterbaths at 20, 23, 26, and 29°C. *P. boryanum* was grown at 25, 30, 35, and 40°C. Cultures were grown under a continuous illumination of about 350 foot candles. Growth and radioactivity determinations were made after 1, 3, 7, 14, and 21 days exposure at the various water temperatures. Data reported represent the mean values of five replicates.

RESULTS AND DISCUSSION

Growth data (Table 2) for the three species at the various water temperatures show that growth rates for *N. seminulum* and *P. boryanum* were inhibited at water temperatures (32°C and 25°C, respectively) slightly above and below the optimum range (Cairns, 1956) reported for diatoms and blue-green algae. *S. lubricum* was not affected significantly by the temperatures tested, but had better growth at 26 and 29°C than at 23 and 32°C. Although not attributable directly to temperature, gross weights of the 14- and 21-day cultures of *N. seminulum* were about twice those of *S. lubricum* and *P. boryanum*. Comparisons with controls showed that algal growth was not affected significantly by the trace concentrations of radionuclides in the media.

Previous studies (Harvey and Patrick, 1967) with these algae have shown that both patterns and levels of radionuclide sorption are generally affected by factors that influence algal growth. The effects of nonlethal elevations in water temperature on the growth of the blue-green alga P. boryanum and its ability to sorb ^{137}Cs, ^{85}Sr, ^{65}Zn, ^{59}Fe, ^{57}Co, and ^{54}Mn has been demonstrated (Harvey, 1969). Sorption patterns in P. boryanum for these radionuclides were similar only in that maximum concentrations were reached during the first 3 days of exposure and radionuclide concentrations in water and algae were usually in equilibrium during the last 14 days of each test. The sorption pattern for ^{57}Co (Figure 1) differed from all others in that concentrations per gram of algae were highest at 25°C and decreased with temperature up to 40°C. The converse was true for concentrations of ^{54}Mn (Figure 2) which increased with temperature up to 35°C. There was no positive correlation between temperatures and sorption patterns for ^{65}Zn, ^{59}Fe, ^{85}Sr, and ^{137}Cs, although the concentration of each radionuclide was slightly higher at 40°C than at lower temperatures.

Growth and radionuclide sorption patterns for the unicellular diatom N. seminulum were much more consistent than those with P. boryanum. These factors were not influenced by water temperatures of 23, 26, and 29°C, as illustrated for ^{57}Co in Figure 3; reduced growth after the third day in 32°C water was reflected in higher concentrations of all test radionuclides.

The water temperatures tested had no significant effect on the growth of the filamentous green alga S. lubricum or its sorption of radionuclides. As illustrated for ^{54}Mn in Figure 4, the radionuclide sorption pattern for S. lubricum generally differed from those of

N. seminulum and P. boryanum in that radionuclide concentrations per gram increased rather than decreased after the third day.

The concentration factors in Table 3 are ratios of the mean radionuclide concentrations per gram dry weight of algae during the last 14 days of each test to the concentrations per ml of ambient medium. These factors may be used to compare the effects of varying temperatures on the ability of a given alga to sorb the test radionuclides, and to compare the relative ability of the three species to sorb radionuclides at a given temperature. The nonessential elements ^{137}Cs and ^{85}Sr were sorbed to lower levels by all three species, and the levels of sorption were not influenced significantly by the temperatures tested. The effects of water temperature on the sorption of the essential elements ^{65}Zn, ^{59}Fe, ^{57}Co, and ^{54}Mn were correlated with growth and were consistent for the diatom N. seminulum, but not for the blue-green alga P. boryanum. In summary, these data show that nonlethal changes in water temperature had no major influence on the sorption of essential or nonessential elements by the algae studied.

TABLE 1

CHEMICAL COMPOSITION OF THE CULTURE MEDIA USED FOR VARIOUS ALGAE[a]

(mg/1 of culture medium)

Compound	*S. lubricum*	*N. seminulum*	*P. boryanum*
KCl	20	20	
$CaCO_3$	10	10	
$MgSO_4.7H_2O$	40	40	25
K_2HPO_4	8	8	10
$Na_2SiO_3.9H_2O$	6.5	179.5	58.7
$Ca(NO_3)_2.4H_2O$	38.1	76.2	230
$NaHCO_3$	40.0	40.0	
NH_4Cl	16.1		
$FeC_6H_5O_7.H_2O$	3.0	3.0	3.0
$C_6H_5O_4(OH)_3$	2.4	2.4	2.4
$Na_2CO_3.H_2O$			
$ZnSO_4.7H_2O$	0.020	0.020	0.020
$MnSO_4.H_2O$	0.014	0.014	0.014
$AlCl_3.6H_2O$	0.036	0.036	0.036
H_3BO_3	0.020	0.020	0.020
LiCl	0.010	0.010	0.010
$CoCl_2.6H_2O$	0.010	0.010	0.010

[a] Distilled water was the base of all media.

TABLE 2

GROWTH OF FRESHWATER ALGAE
AT VARIOUS WATER TEMPERATURES

(mg dry weight)

Days Exposed	*S. lubricum*	*N. seminulum*	*P. boryanum*
	23°C	23°C	25°C
1	1.7 ± 0.2	1.5 ± 0.2	1.7 ± 0.2
3	2.5 ± 0.7	3.2 ± 1.1	2.5 ± 0.5
7	5.0 ± 1.2	10.6 ± 4.1	4.0 ± 1.9
14	12.1 ± 3.6	27.2 ± 8.3	7.2 ± 3.1
21	20.8 ± 8.1	60.5 ± 11.5	10.0 ± 1.9
	26°C	26°C	30°C
1	1.4 ± 0.1	1.4 ± 0.2	1.6 ± 0.5
3	2.7 ± 0.2	3.6 ± 1.3	3.6 ± 1.2
7	5.6 ± 1.2	13.1 ± 5.7	6.0 ± 3.2
14	15.6 ± 2.9	34.8 ± 10.2	11.4 ± 3.7
21	24.8 ± 8.4	67.1 ± 8.0	19.2 ± 3.7
	29°C	29°C	35°C
1	1.2 ± 0.1	1.4 ± 0.3	1.8 ± 0.4
3	3.4 ± 1.2	4.2 ± 1.1	3.5 ± 1.1
7	7.6 ± 2.5	13.9 ± 4.1	5.3 ± 2.1
14	18.6 ± 6.2	47.3 ± 12.3	13.1 ± 5.7
21	25.6 ± 6.1	63.1 ± 14.1	20.1 ± 8.0
	32°C	32°C	40°C
1	1.2 ± 0.2	1.6 ± 0.1	1.6 ± 0.4
3	2.4 ± 0.5	3.3 ± 1.4	2.1 ± 0.5
7	4.8 ± 1.6	5.6 ± 1.4	3.0 ± 0.6
14	11.8 ± 3.4	19.0 ± 5.7	10.4 ± 1.8
21	17.0 ± 7.2	29.3 ± 4.1	21.9 ± 4.0

TABLE 3

RADIONUCLIDE CONCENTRATION FACTORS FOR FRESHWATER ALGAE

$$\left(\frac{\mu Ci/g \text{ of algae}}{\mu Ci/l \text{ of culture medium}} \right)$$

Radionuclide	S. lubricum	N. seminulum	P. boryanum
	23°C		25°C
^{137}Cs	830	1450	1000
^{85}Sr	1250	600	2300
^{65}Zn	34800	16400	22000
^{59}Fe	2300	6900	2600
^{57}Co	27100	10300	6200
^{54}Mn	36600	11100	15300
	26°C		30°C
^{137}Cs	850	1400	1000
^{85}Sr	1230	650	2000
^{65}Zn	32800	16700	26500
^{59}Fe	2400	7400	2400
^{57}Co	28800	11400	4500
^{54}Mn	39700	9900	27700
	29°C		35°C
^{137}Cs	910	1200	900
^{85}Sr	1160	750	2300
^{65}Zn	30300	16600	22000
^{59}Fe	2500	7100	2700
^{57}Co	29700	10700	3500
^{54}Mn	47000	10500	35300
	32°C		40°C
^{137}Cs	980	1300	1100
^{85}Sr	1330	600	3000
^{65}Zn	31100	27900	33500
^{59}Fe	3600	14900	3200
^{57}Co	27500	19900	2500
^{54}Mn	44100	20400	27900

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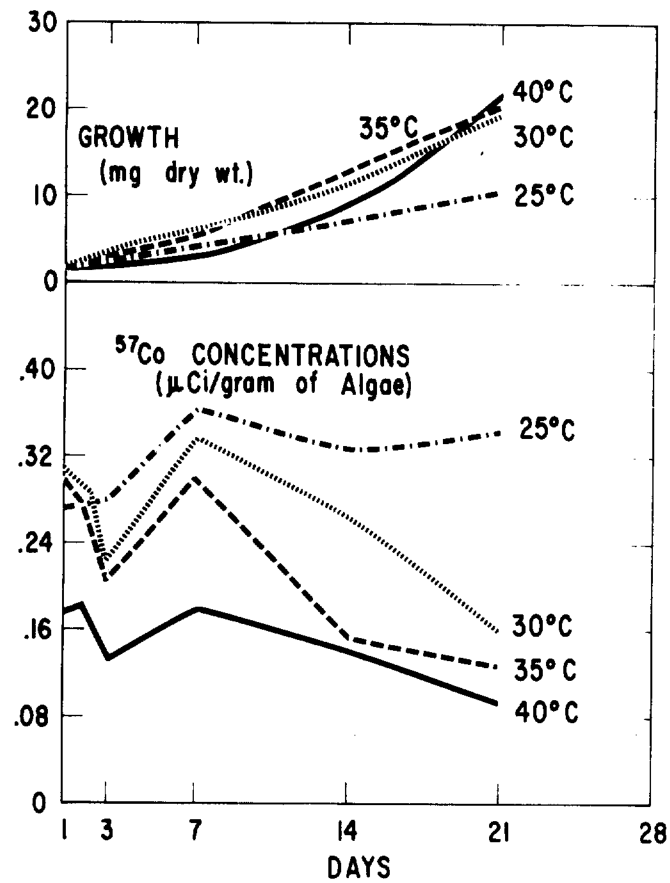

FIG. 1 GROWTH AND ^{57}Co SORPTION PATTERNS FOR THE BLUE-GREEN ALGA, PLECTONEMA BORYANUM, AT VARIOUS WATER TEMPERATURES

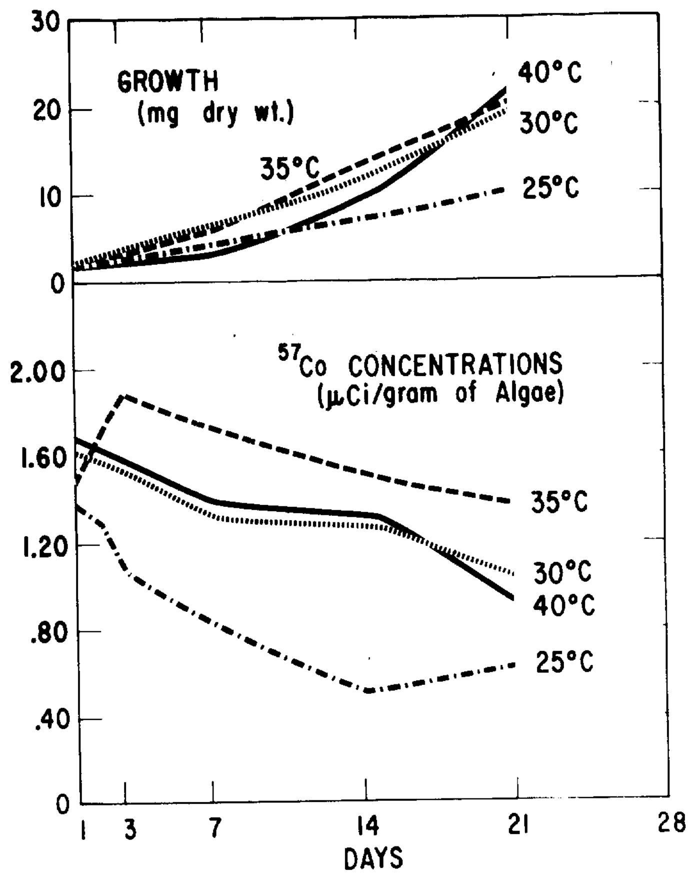

FIG. 2 GROWTH AND ^{54}Mn SORPTION PATTERNS FOR THE BLUE-GREEN ALGA, *PLECTONEMA BORYANUM*, AT VARIOUS WATER TEMPERATURES

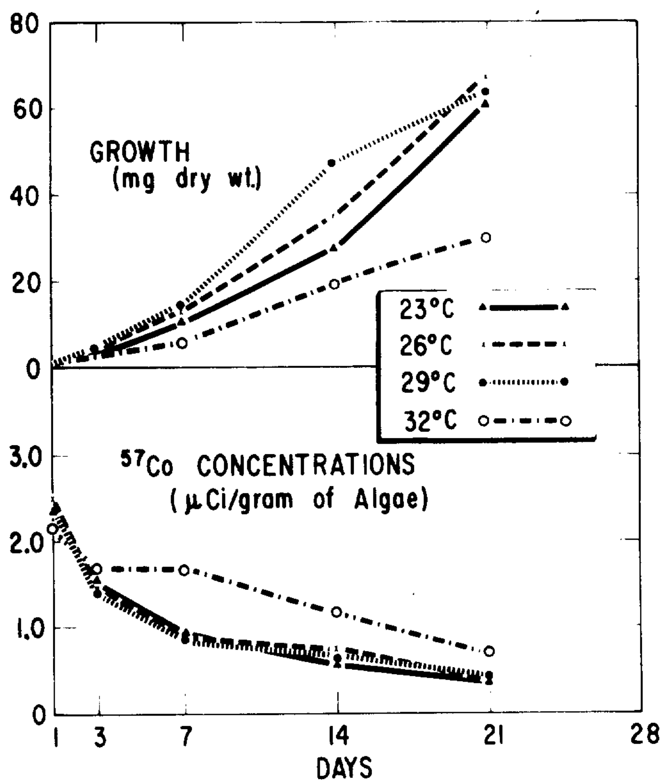

FIG. 3 GROWTH AND ^{57}Co SORPTION PATTERNS FOR THE DIATOM, *NAVICULA SEMINULUM*, AT VARIOUS WATER TEMPERATURES

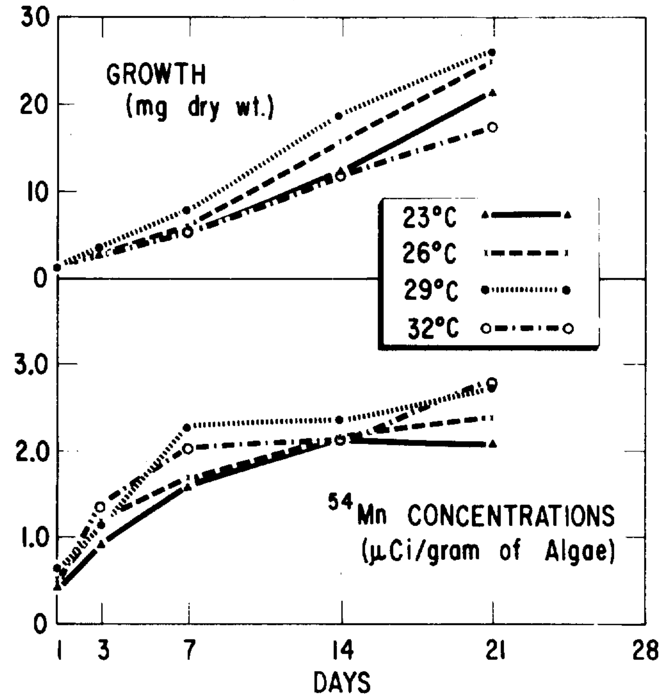

FIG. 4 GROWTH AND ^{54}Mn SORPTION PATTERNS FOR THE GREEN ALGA, STIGEOCLONIUM LUBRICUM, AT VARIOUS WATER TEMPERATURES