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REMOVAL OF NUTRIENTS IN ALGAL-BACTERIAL PONDS — LABORATORY EXPERIMENTS

The experiments, aimed at determining the degree of nutrient removal from algal-bacterial ponds, were conducted in two series. In the first series the water was taken from drainage ditch, while in the second one it was additionaly enriched with nutrients.

The experimental system consisted of four ponds. Algae were removed from the ponds 1 and 2 in a natural way being the food for *Daphnia magna* introduced into the pond 3. *Lemna minor* was introduced into pond 4 in order to remove the nitrogen and phosphorus compounds not utilized by algae.

A high (up to 100%) removal of ortophosphates stated in both experimental series increased with theoretical time of drainage water flow.

In the experiments with drainage water (enriched with nutrients) the removal of total phosphorus reached 86%, the degree of total nitrogen removal being also very high.

The percent of ammonium nitrogen removal was, in general, higher for the water containing higher initial concentrations of this compound. In the case of nitrates the removal degree was higher for water without addition of nutrients.

The total increment of the number of algae, *D. magna* and *L. minor* was higher in drainage water enriched with nutrients. It has been also observed that the increment of the number of *L. minor* was inversely proportional to that of algae.

1. INTRODUCTION

Mass algal blooms and subsequent decay of organic matter as a consequence of eutrophication results in numerous negative phenomena leading to high oxygen deficiencies and the release of hydrogen sulphide, carbon dioxide, dissolved iron and manganese. The decrease of euphotic zone to 0.2 m is always noted and problems with water purification are outstanding.

The algal bloom requires nitrogen, phosphorus and carbon; the minimum or threshold amounts of nitrogen and phosphorus being respectively 0.3 mg/dm^3 and 0.01 mg/dm^3 [7, 12, 13].

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Nitrogen and phosphorus compounds may be removed by chemical and/or physical methods. Phosphorus removal is achieved by coagulation and chemical precipitaiton with sedimentation and filtration. Nitrogen can be removed in gaseous desorption, selective ion exchange on the clinoptilolyte or during chlorination to the breakthrouh point. Inorganic forms of nitrogen and phosphorus (PO_4, NO_3, NH_4) may be removed also during demineralization, i.e.: during reverse osmosis, electrodialysis or distillation. Nitrogen and phosphorus are also partially removed during biosynthesis on biofilters and in activated sludge tanks.

Oxidation ponds gain an ever growing popularity in the technology of wastewater treatment. They are placed under the foil to improve heat balance and utilize the energy of sun for bioassimilation.

The costs of the raw wastewaters treatment by natural biological processes yielding water of high quality constitute 50% of the purification costs by conventional methods. Construction and operation of an aquaculture system that allows to obtain the same quality of water as after conventional secondary biological treatment is on the average 50% cheaper. Reusable water quality may be obtained in this system at the costs four times lower than that required in the average tertiary treatment plant [14].

In conventional treatment systems most of the harmful pollutants, such as pesticides, phenols, heavy metals and certain carcinogens, are neither removed nor neutralized. In the ecological systems nutrients are reduced, numerous dangerous chemical compounds detoxicated and pathogenetic bacteria and viruses are removed. The additional advantage of this particular method is the possible recovery of a number of valuable products [14].

Water plants grown in the algal ponds may be used as a food or an admixture to the fodder for fish, swine and cattle, they may also be utilized as organic fertilizers.

The purpose of the experiments was to remove the nutrients in the drainage effluents from the fields irrigated with wastewater as well as to improve economics by harvesting the plant and crustacean biomass.

2. METHODS AND MATERIALS

2.1. MATERIALS

Water was taken from the drainage ditch which carried drainage effluents from fields irrigated by gravitation and sprinkling systems.

Investigations were carried out with unicellular algae *Chlorella* sp. and *Scenedesmus* sp., coming from batch cultures growing on the medium prepared according to Polish Standards [8],

Lemma minor (duckweed) cultured in an inorganic medium supplemented with microelements, according to GORHAM [2],

Daphnia magna, representing *Cladocera*, cultured in tap water.

2.2. EXPERIMENTAL PROCEDURES

Physicochemical analyses of water outflowing from the system, the counts of algae and bacteria in the first two aquriums and that of *L. minor* in the last one were conducted at the beginning, during and at the end the of experiment, the increment of *D. magna* mass was being determined at the end of the experiment.

The number of psychrophilic and mesophilic bacteria was determined from the number of colonies grown on agar at 20°C and 37°C after 72 and 24 hours, respectively.

The number of algae was determined by microscopic method, by the total number of cells in Fuhs-Rosenthal chamber per 1 ml of water. Increase of *D. magna* was defined by the increase of its dry matter in the experiment set-up during the whole period. The number of *L. minor* plants was determined by the number of trisegment plant sprouts or by their dry matter.

The analyses, performed according to [5, 6, 9-11], included dissolved oxygen, BOD_5, PV, calcium, alkalinity, N-NO_3, total nitrogen (TKN) and phosphorus, N-NO_2, N-NH_4, PO_4 and pH.

2.3. EXPERIMENTAL SET-UP

The system consisted of four connected aquariums (fig. 1). The two first ones were inocculated with *Chlorophyta*, the third one with *D. magna*, and the last one with *L. minor*.

Each experiment was carried out in two parallel systems with different quality of the influent drainage water. The first (system A) was fed with water from the drainage ditch,

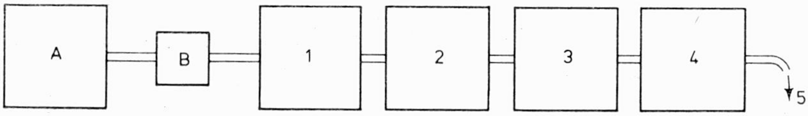

Fig. 1. Diagram of experimental set

A – aquarium with supplying wastewater; B – metering pump; 1, 2 – aquariums with algae; 3 – aquarium with *D. magna*; 4 – aquarium with *L. minor*; 5 – outlet

Rys. 1. Schemat układu doświadczalnego

A – zbiornik zasilający; B – pompa dozująca; 1, 2 – zbiorniki bakteryjno-glonowe; 3 – zbiornik z *D. magna*; 4 – zbiornik z *L. minor*; 5 – odpływ

the second one (system B) with the same water additionaly enriched with nutrients in the amount characteristic of the water quality exceeding the III class standards. Nitrogen and phosphorus were added in system B in the following forms: $(NH_4)_2SO_4$, KNO_3, and K_2HPO_4. $NaHCO_3$ (applied continuously) or CO_2 (applied for several hours a day) were the source of carbon. Iron (3 mg/dm^3) was added either in the form of $FeCl_3$ or mono-sodium-ferric salt of EDTA (ethene diamine tetra-acetic acid). Water flow was provided by metering pumps from the supply tank.

A period of 16 hours of continuous illumination was alternated by 8 hours of darkness. Available light on the surface of the tanks amounted to 4 700 Lxs.

Ambient temperature for consecutive experiments varied within: 16-34°C, 18-28°C, 17-25°C, and 18-30°C, respectively. Usually the temperature ranged from 20-25°C.

The experiments 1-4 were conducted for 15, 25, 16, and 25 days, respectively.

Theoretical hydraulic retention time (HRT) of the drainage water with low concentration of nutrients (system A) ranged from 10.8-15.9 days, while for the water with high concentrations (system B) HRT = 10.5-15.6 days.

3. RESULTS

3.1. ORTHOPHOSPHATES

Fig. 2 presents the changes in the orthophosphates concentrations in the effluent for four experiments. Each experiment was carried out in two systems: A — one with low (0.09-0.48 mg/dm^3) initial concentration of orthophosphates; in the second one (B) with high content (2.3-9.8 mg/dm^3). Except for one case of low input (0.09 mg/dm^3) otherwise high removals were observed; the $P\text{-}PO_4$ removals increased with the HRT, and in most cases exceeded 90% on the 10th day, reaching 100% after several days.

Changes in $P\text{-}PO_4$ and total phosphorus content are shown in fig. 3. At high initial concentrations of phosphorus compounds ($P_{tot.}$ — 13.6 mg/dm^3, $P\text{-}PO_4$ — 9.8 mg/dm^3), as much as 86% of $P_{tot.}$ and 98.5% of $P\text{-}PO_4$ were removed as early as on the 12th day.

Theoretical retention time of wastewaters in the experiments ranged from 11-16 days. The percentage of phosphates removal increased with the retention time of the examined wastes in the aquariums.

In the systems with high nutrients loads (B) the removal of $P\text{-}PO_4$ was high at shorter HRT-s (fig. 4). At low initial $P\text{-}PO_4$ (A) (0.09 mg/dm^3) the $P\text{-}PO_4$ removals were not correlated with flow.

3.2. NITROGEN COMPOUNDS

Changes in the ammonia nitrogen ($N\text{-}NH_4$) content in the effluent are shown in fig. 5. A high degree of $N\text{-}NH_4$ removal was achieved at initial concentrations of 3.1-7.6 mg/dm^3. Even if the concentration of $N\text{-}NH_4$ increased at first (up to 5 days), it then successively decreased. After 10th-16th day the removal exceeded 95%.

High changes in the concentration of ammonium salts were found in the system with smaller nitrogenous loads. The overall removals were usually lower than that in the more loaded systems (B) and amounted to 18, 33.3, and 50 after 25, 16, and 25 days, respectively.

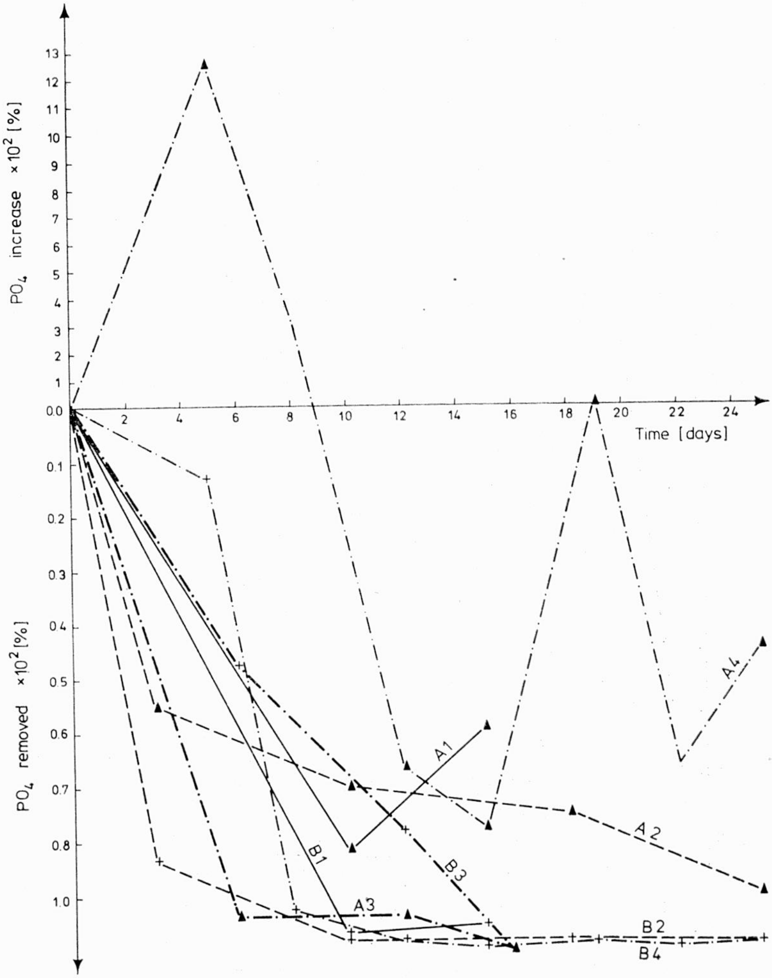

Fig. 2. Ortophosphates removal in algal-bacterial ponds

A1-A4 — ortophosphates initial concentrations equal to 0.09-0.48 mg/dm^3; **B1-B4** — ortophosphates initial concentrations equal to 2.30-9.80 mg/dm^3

Rys. 2. Usuwanie ortofosforanów w stawach bakteryjno-glonowych

A1-A4 — stężenie początkowe ortofosforanów 0,09-0,48 mg/dm^3; **B1-B4** — stężenie początkowe ortofosforanów 2,30-9,80 mg/dm^3

The initial concentrations of nitrites were 0.008-0.02 mg/dm^3 and 0.01-0.029 mg/dm^3 for systems A and B, respectively. In systems of the B series, $N-NO_2$ concentration was increasing during the first 10 days of the experiment (fig. 6), thereupon it either remained high being 100 times higher than the initial concentration (as in the experiment 4) or it decreased by 57% (as in the experiment 2) except for experiment 3 which was different.

The experiments performed in the system series A (without nutrients) were characterized by visibly lower increase of $N-NO_2$ concentration. Only in the experiment 2 the $N-NO_2$

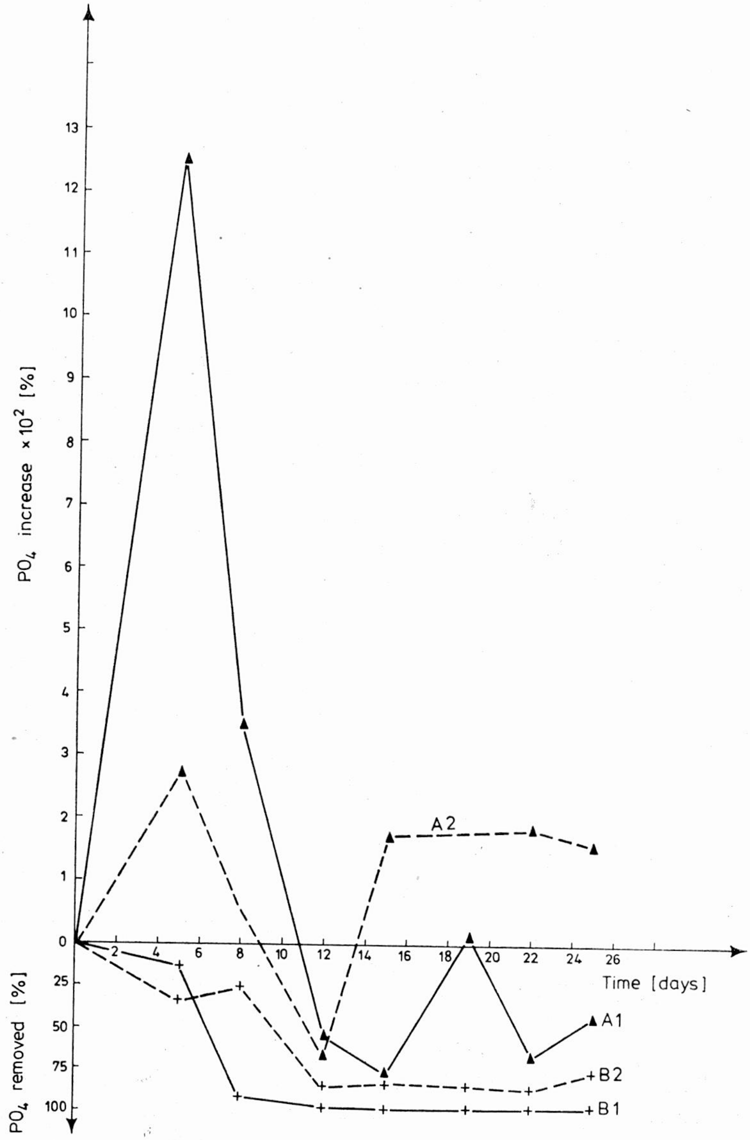

Fig. 3. Phosphorus compounds removal in algal-bacterial ponds

A1 — $P\text{-}PO_4$ initial concentration equal to 0.09 mg/dm³; B1 — $P\text{-}PO_4$ initial concentration equal to 9.80 mg/dm³; A2 — P tot. initial concentration equal to 0.41 mg/dm³; B2 — P tot. initial concentration equal to 13.60 mg/dm³

Rys. 3. Usuwanie związków fosforu w stawach bakteryjno-glonowych

A1 — stężenie początkowe $P\text{-}PO_4$ 0,09 mg/dm³; B1 — stężenie początkowe $P\text{-}PO_4$ 9,80 mg/dm³; A2 — stężenie początkowe P ogl. 0.41 mg/dm³; B2 — stężenie początkowe P ogl. 13,60 mg/dm³

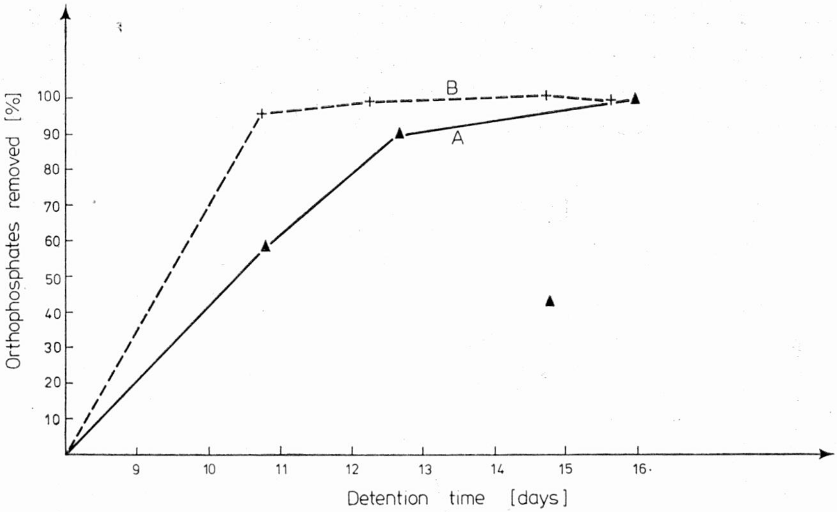

Fig. 4. Percentage of P-PO_4 removal versus flow time

A — no nutrients added; B — nutrients added

Rys. 4. Procent usunięcia P-PO_4 w zależności od czasu przepływu

A — układ bez dodatku związków biogennych; B — układ z dodatkiem związków biogennych

concentration was higher than the initial one, throughout the whole experiment, and reached the highest value on the 10th day (0.048 mg/dm^3). In other cases the removal varied, reaching even 100% (experiments 1 and 4).

For the A systems (with small nitrates amount) and for the B systems the initial concentrations were 0.44-2.89 mg N-NO_3/dm^3 and 9.48-35.36 mg N-NO_3/dm^3, respectively. In the parallel experiments with higher N-NO_3 concentrations, the removal was visibly lower. The maximal N-NO_3 removal (fig. 7), i.e. 50%, occurred after 15 days (experiment 1) and 19 days (experiment 2). Experiment 3 was characterized by the increase of N-NO_3 concentration. In the A system series the N-NO_3 increase was remarkably higher compared with the B series, i.e. with added nutrients. This is explained by intensive nitrification. The increase of nitrates was accompanied by the decrease of N-NH_3 concentrations. Dissolved oxygen in experiment 3, both A and B series, exceeded 8 mg O_2/dm^3. No correlation was found between the duration of experiment and the N-NO_3 content or removal.

Changes in the concentrations of N-NH_4, N-NO_3, TKN and N_{org}, occurring in the different systems in parallel experiments, are shown in fig. 8. In the A system series the concentrations of N_{org} and TKN were higher than the initial ones, and after the last 25th day of experiment these concentrations were: 1 mg N_{org}/dm^3 (initial concentration 0.9 mg/dm^3) and 1 mg TKN/dm^3 (initial concentration 0.98 mg/dm^3). A slight increase of TKN may be due to the increased amount of N_{org}, as TKN = N_{org}+N-NH_4. Organic nitrogen came probably from the disintegrated algal cells which were introduced together with the living algae. In the B system series the content of N_{org} and TKN were 19.37 mg/dm³ and 27.05 mg/dm³, respectively, and during the experiment decreased continuously; on the 25th day of the experiment the N_{org} and TKN removals were 91% and 89%, respectively.

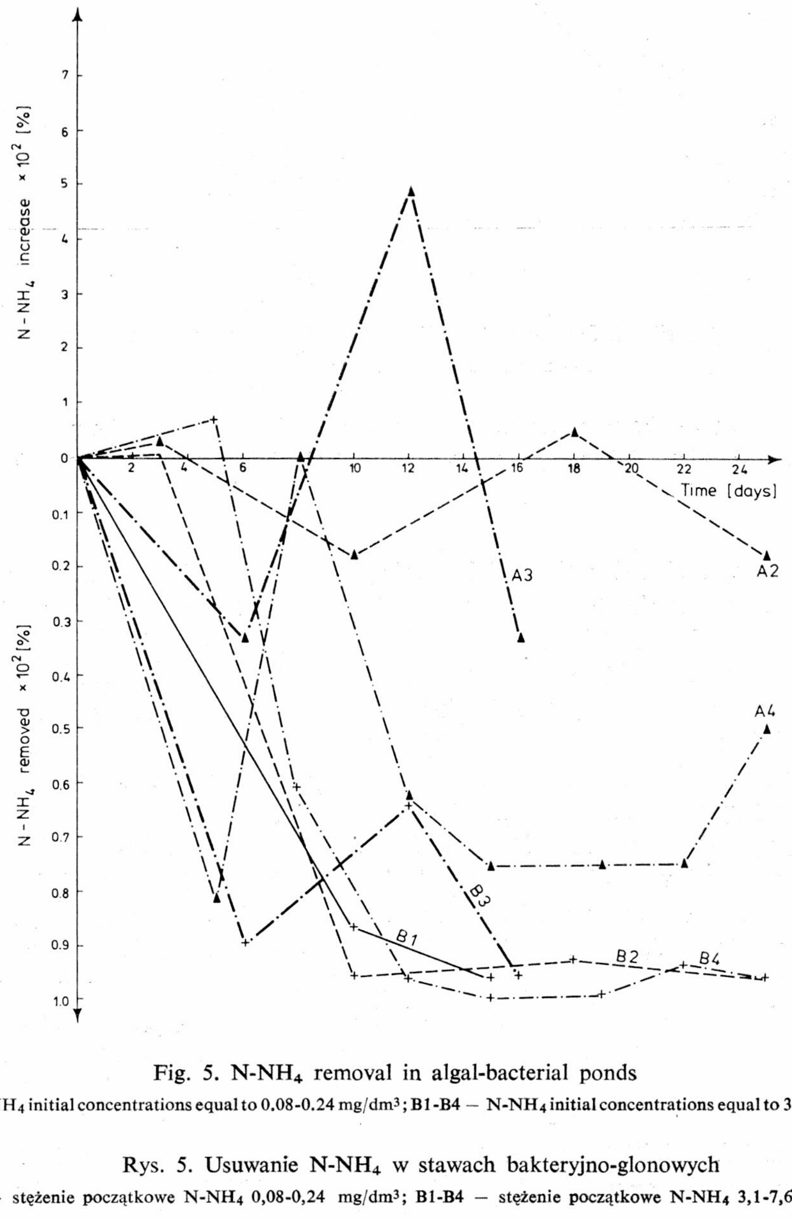

Fig. 5. $N\text{-}NH_4$ removal in algal-bacterial ponds

A2-A4 — $N\text{-}NH_4$ initial concentrations equal to 0.08-0.24 mg/dm³; B1-B4 — $N\text{-}NH_4$ initial concentrations equal to 3.1-7.68 mg/dm³

Rys. 5. Usuwanie $N\text{-}NH_4$ w stawach bakteryjno-glonowych

A2-A4 — stężenie początkowe $N\text{-}NH_4$ 0,08-0,24 mg/dm³; B1-B4 — stężenie początkowe $N\text{-}NH_4$ 3,1-7,68 mg/dm³

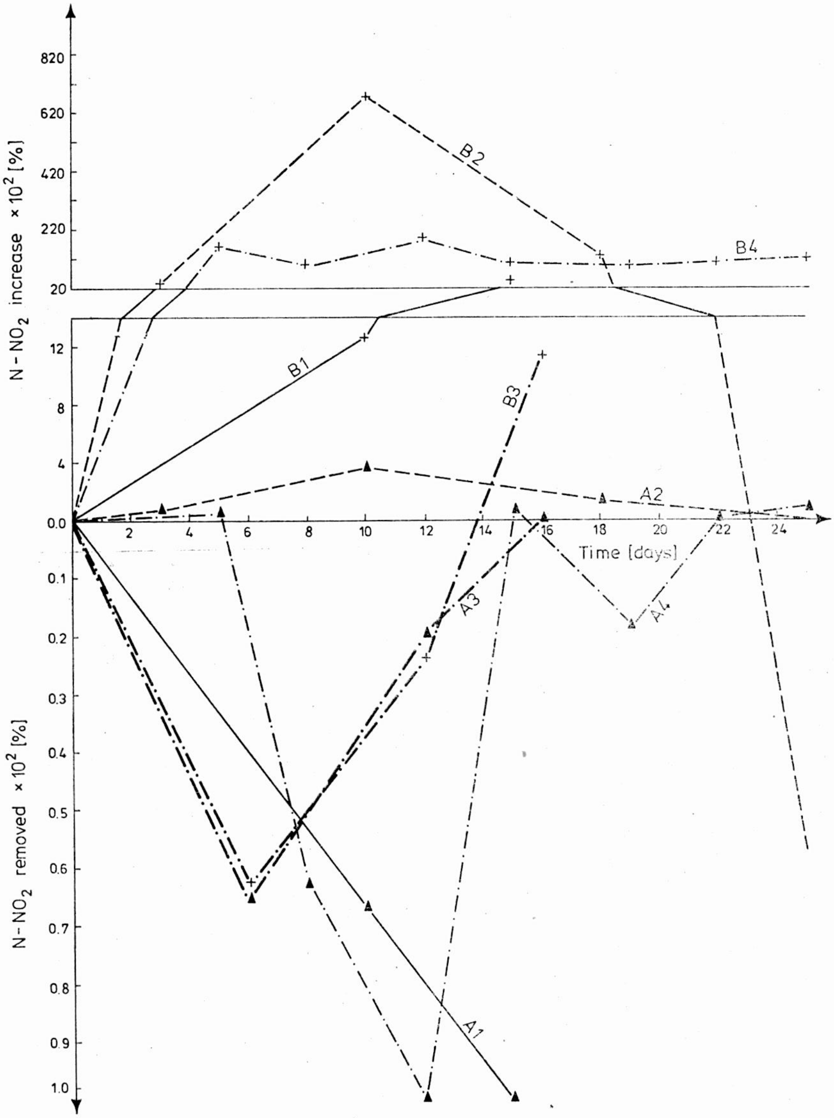

Fig. 6. N-NO_2 removal in algal-bacterial ponds

A1-A4 – N-NO_2 initial concentrations equal to 0.008-0.020 mg/dm³; B1-B4 – N-NO_2 initial concentrations equal to 0.010-0.029 mg/dm³

Rys. 6. Usuwanie N-NO_2 w stawach bakteryjno-glonowych

A1-A4 – stężenie początkowe N-NO_2 0,008-0,020 mg/dm³; B1-B4 – stężenie początkowe N-NO_2 0,010-0,029 mg/dm³

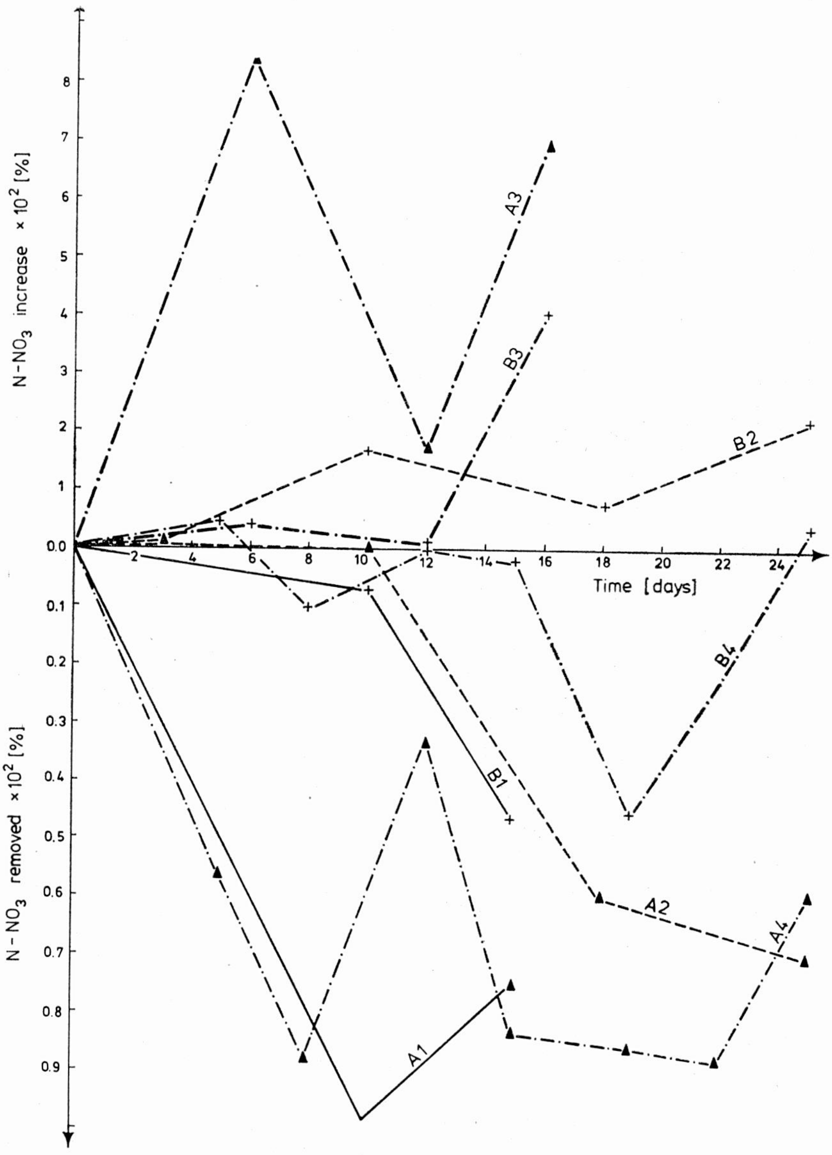

Fig. 7. N-NO_3 removal in algal-bacterial ponds

A1-A4 – N-NO_3 initial concentrations equal to 0.44-2.98 mg/dm^3; B1-B4 – N-NO_3 initial concentrations equal to 9.48-35.36mg/dm^3

Rys. 7. Usuwanie N-NO_3 w stawach bakteryjno-glonowych

A1-A4 – stężenie początkowe N-NO_3 0,44-2,98 mg/dm^3; B1-B4 – stężenie początkowe N-NO_3 9,48-35,36 mg/dm^3

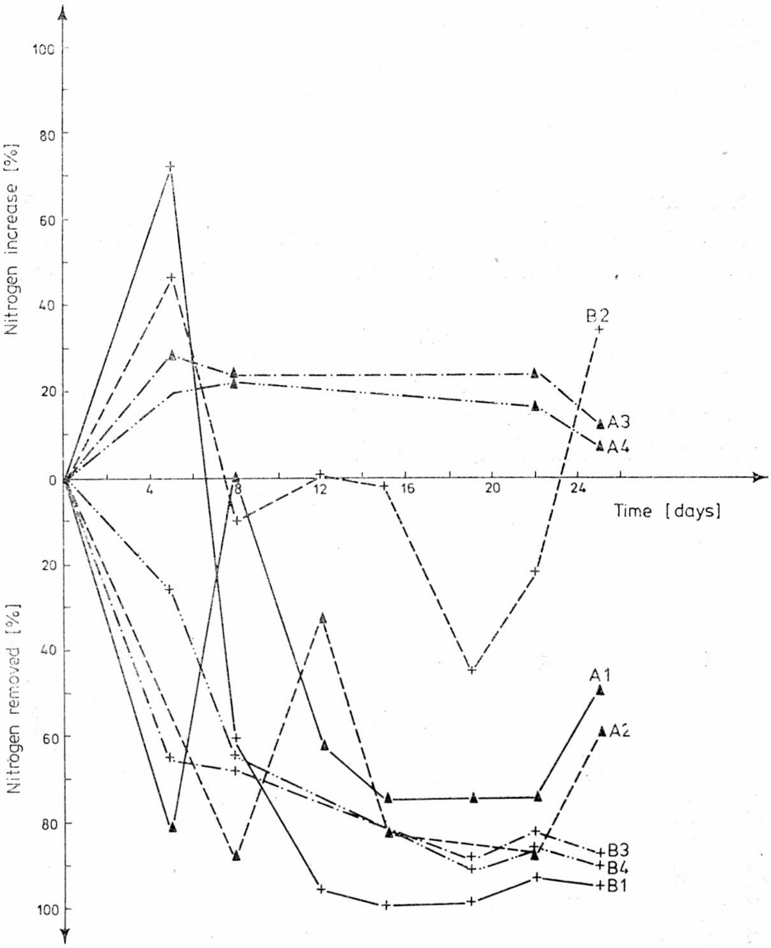

Fig. 8. Nitrogen compounds removal in algal-bacterial ponds

A1 — N-NH_4 initial concentration equal to 0.08 mg/dm^3; B1 — N-NH_4 initial concentration equal to 7,68 mg/dm^3; A2 — N-NO_3 initial concentration equal to 0.84 mg/dm^3; B2 — N-NO_3 initial concentration equal to 35.36 mg/dm^3; A3 — N org. initial concentration equal to 0.90 mg/dm^3; B3 — N org. initial concentration equal to 19.37 mg/dm^3; A4 — TKN initial concentration equal to 0.98 mg/dm^3; B4 — TKN initial concentration equal to 27.05 mg/dm^3

Rys. 8. Usuwanie związków azotu w stawach bakteryjno-glonowych

A1 — stężenie początkowe N-NH_4 0,08 mg/dm^3; B1 — stężenie początkowe N-NH_4 7,68 mg/dm^3; A2 — stężenie początkowe N-NO_3 0,84 mg/dm^3; B2 — stężenie początkowe N-NO_3 35,36 mg/dm^3; A3 — stężenie początkowe N org. 0,90 mg/dm^3; B3 — stężenie początkowe N org. 19,37 mg/dm^3; A4 — stężenie początkowe N całk. 0,98 mg/dm^3; B4 — stężenie początkowe N całk. 27,05 mg/dm^3

3.3. DISSOLVED OXYGEN

In all experimental systems in which nutrients were added (B series), the content of the dissolved oxygen (DO) in the effluent was always higher than in A series and in both systems exceeded 8 mg O_2/dm^3. At times (in the B systems) DO reached 20 mg O_2/dm^3, which was due to photosynthesis of large biomass of algae and duckweed on salt enriched water. In the A system series (without nutrients) the biomass of algae and duckweed was smaller, hence, the DO levels were lower.

3.4. pH OF WATER

In the experiments 1, 2 and 3 (systems with low nitrogen and phosphorus contents) the pH ranged from 7.0-8.2. In the experiment 4 it was 8.0-8.4. In the systems with higher nutrient contents and in the experiment 4 the pH was 7.2-9.1 and 7.9-8.3, respectively.

3.5. BACTERIA

The initial numbers of mesophilic and psychrophilic bacteria in the A system varied from 1×10^3-9×10^4 and from 22×10^3-32×10^4, respectively. Their numbers, however, in the B system varied on the 1st day from 1.6×10^3-64×10^3 and from 12×10^3-61×10^4,

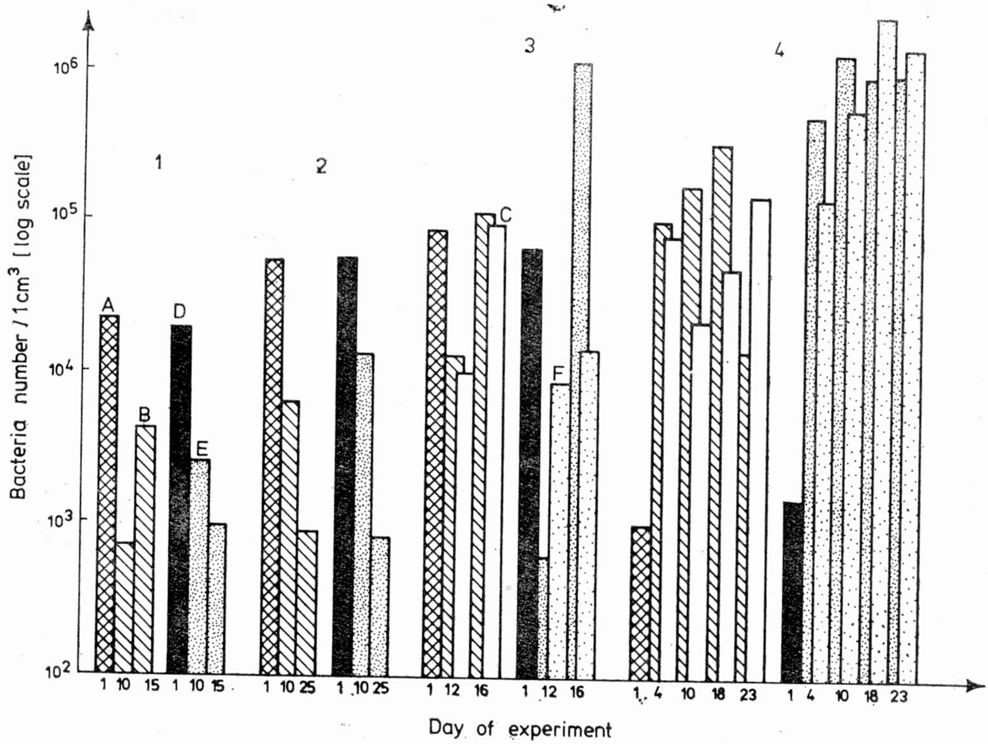

Fig. 9. Changes of mesophilic bacteria number during the experiment

A, D — initial bacteria number; B, E and C, F — bacteria number in 1 and 2 aquariums, respectively; A, B, C — system A (no nutrients added); D, E, F — system B (with nutrients added)

Rys. 9. Zmiany liczby bakterii mezofilnych w układzie doświadczalnym

A, D — początkowa liczba bakterii; B, E — liczba bakterii w zbiorniku 1; C, F — liczba bakterii w zbiorniku 2; A, B, C — układ A (bez dodatku związków biogennych); D, E, F — układ B (z dodatkiem związków biogennych)

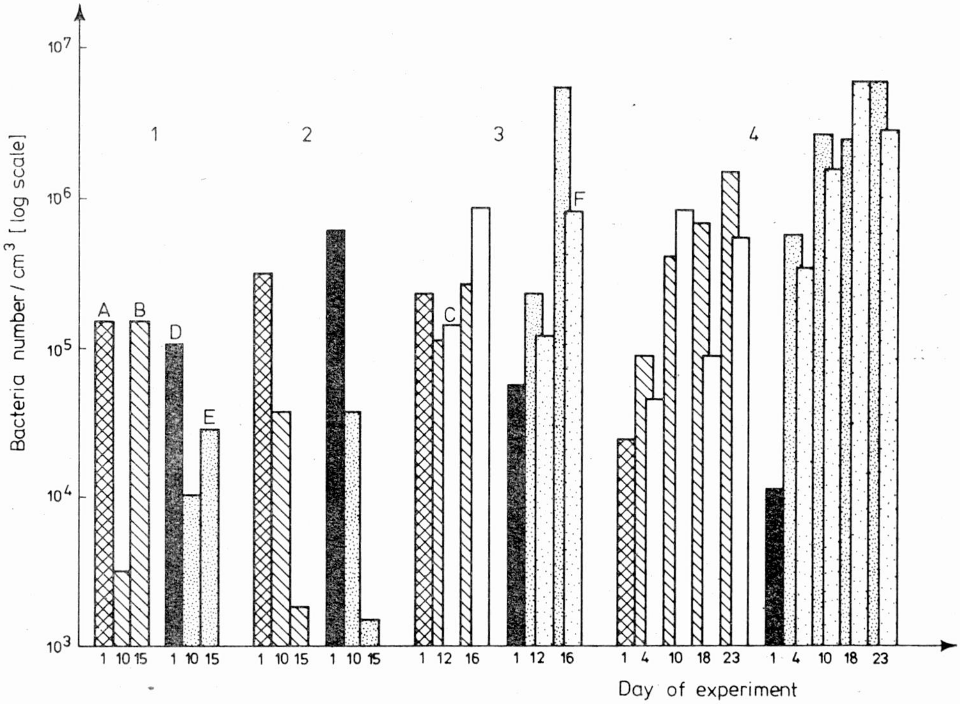

Fig. 10. Changes of psychrophilic bacteria number during the experiment

For explanations see fig. 9

Rys. 10. Zmiany liczby bakterii psychrofilnych w układzie doświadczalnym

Objaśnienia jak do rys. 9

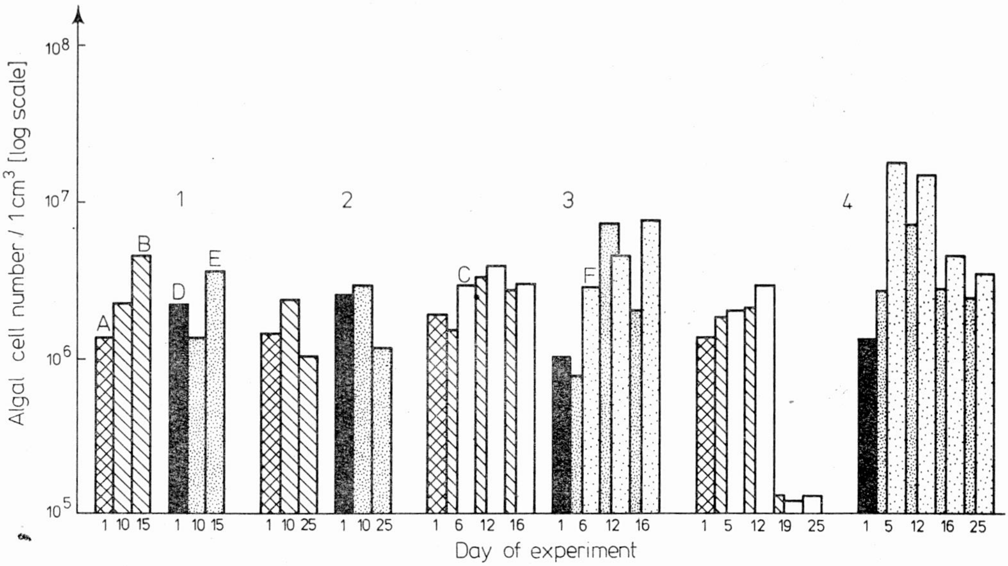

Fig. 11. Changes of algal cell number during the experiment

A, D — initial algal cell number; B, E and C, F — algal cell number in 1 and 2 aquariums, respectively; for other explanations see fig. 9

Rys. 11. Zmiany liczby komórek glonów w układzie doświadczalnym

A, D — początkowa liczba komórek glonów; B, E — liczba komórek glonów w akwarium 1; C, F — liczba komórek glonów w akwarium 2; inne objaśnienia jak do rys. 9

respectively (figs. 9, 10). In the experiments 1 and 2 the numbers of mesophilic and psychrophilic bacteria at the end and during the experiment were smaller than the initial ones. In both systems A and B in experiment 3 the bacterial counts after 12 days were smaller than the initial ones. In the A system the final number of psychrophilic bacteria exceeded several times the initial one. In the experiment 4 numbers of mesophilic and psychrophilic bacteria were the lowest (fig. 12) on the first day in both A and B series. The number of bacteria was changing during the experiment but it always exceeded the initial values. The numbers of mesophilic and psychrophilic bacteria in the B series (with nutrients) many times exceeded the numbers in the A series.

3.6. ALGAE

After inocculation with *Chlorella* sp. and *Scenedesmus* sp. the initial number of algae cells in 1 ml of waste examined ranged between 141×10^4 and 187×10^4 in system A, and varied from 104×10^4-210×10^4 in system B (fig. 11). In the experiment 1 the number of algae in system A after 10 and 15 days exceeded their initial value. In system B the number of algae after 10 days was smaller than the initial one (it is explained by the adaptation), the highest number was observed on the 15th day. In the experiment 2 (both systems) the number of algae on the 10th day was higher, while on the 15th day lower than the ini-

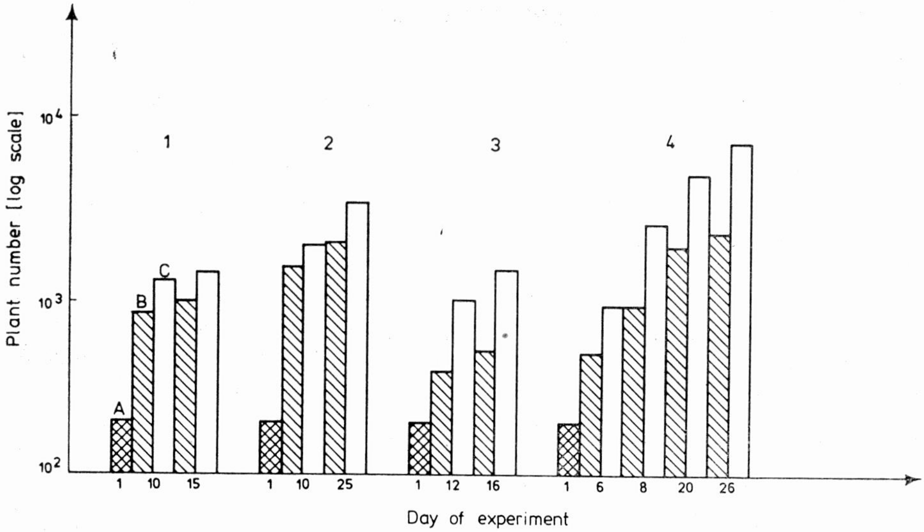

Fig. 12. Increment of *L. minor* during the experiment

A – initial number of *L. minor*; B – final number of *L. minor* in A system; C – final number of *L. minor* in B system

Rys. 12. Przyrost *L. minor* w układzie doświadczalnym

A – początkowa liczba *L. minor*; B – końcowa liczba *L. minor* w układzie A; C – końcowa liczba *L. minor* w układzie B tial one. In experiment 3 (both systems) the numbers of algae in aquariums were on the 6th day lower than the initial ones. On the remaining days the numbers still substantially exceeded the initial values, as in experiment 4. It was found in most cases that the number of algae in aquarium II of the given system exceeded that number in aquarium I. The system B series had higher numbers of algae than that system A except for the experiment 1.

3.7. *DAPHNIA MAGNA*

In experiments 1, 2 and 3 *D. magna* was introduced into tank III. The amount of *D. magna* introduced on the first day of the experiment was simultaneously the initial amount for the whole system. Its amount for experiments 1, 2 and 3 was equal to 62.1 mg, 11 mg and 11 mg of dry matter, respectively. During the experiment daphnia passed from the tank III to neighbouring ones, on the last day it was collected from the tanks II, III and IV, i.e. from the volume of 30 dm^3. The results are shown in fig. 13. In all cases the increase of *D. magna* dry matter biomass (d.m.) was higher in B than in A systems and in experi-

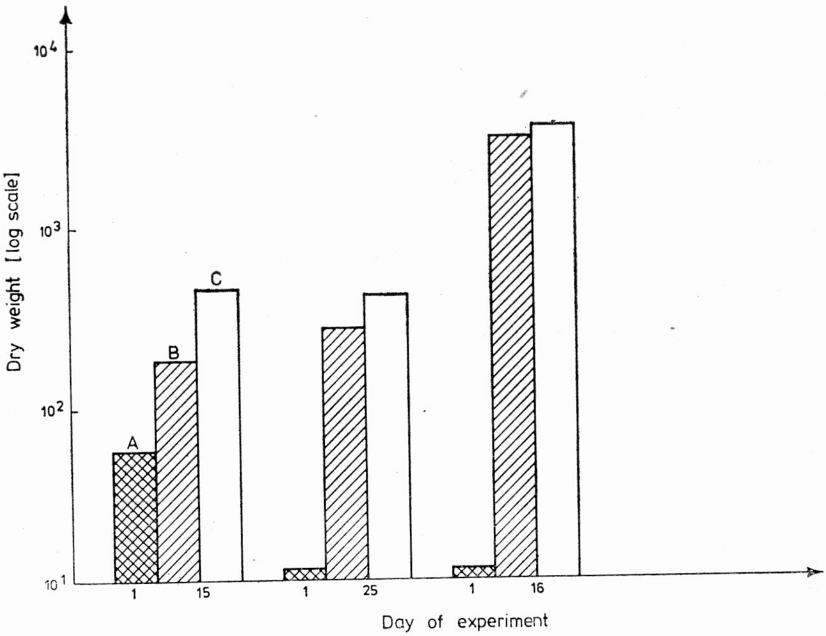

Fig. 13. Increment of *D. magna* during the experiment

A – initial dry weight of *D. magna*; B – final dry weight of *D. magna* in A system; C – final dry weight of *D. magna* in B system

Rys. 13. Przyrost *D. magna* w układzie doświadczalnym

A – początkowa sucha masa *D. magna*; B – końcowa sucha masa *D. magna* w układzie A; C – końcowa sucha masa *D. magna* w układzie B ment 1 on the 15th day was equal to 181.7 mg and 4 445.7 mg for A and B systems, respectively. The highest dry matter increase was found in experiment 3 and was on the 16th day 283 times higher than the initial one in system A and 339 times in B system.

3.8. *LEMNA MINOR*

L. minor individuals, covering the surface of the aquarium IV in the experiments 1, 2 and 3, consisted of 200 dimerous sprouts, the third one being in the course of development. In all experiments the increase in the number of *L. minor* individuals was higher for the B series (fig. 12). In experiment 2, system A, the population of *L. minor* after 25 days comprised 2 080 individuals, while in system B (with nutrients) a similar number (2 027) was found as early as on the 10th day. In the B system series the final number of plants (after 16 days) was 3 times higher than that in the A system series. In experiment 4 *L. minor* was grown in the aquarium III. For each system the initial number of plants with three sprouts was equal to 200 individuals (0.035 g d.m.). In the A system series the number of plants after 26 days was 11 times higher at the beginning when there were 2 280 specimens. At the same time its dry matter increased 35 times. It was found that in the B system the number of *L. minor* after 26 days increased from 200-7 470 plants. While the number of plants increased 37 times, the dry matter was 152.8 times higher than the initial one. *L. minor* growing in the systems with added nutrients was of dark green colour and had small leaves and short roots, whereas *L. minor* in the systems with low nutrient concentration had large, light green leaves and long roots.

4. DISCUSSION

It was found in the above experiments that algae are able to remove orthophosphates to a high degree (up to 100%). A higher degree of phosphates removal awas achieved in shorter time for the experiments with higher initial concentration of these compounds (system B series), except for the experiment 3, in which the removal on the 6th and 12th day was higher when the nutrients were not added (system A). It could be due to larger amount of algae present in water during the first part of the experiment. In neither system the presence of phosphates was stated in the effluent on the 16th day. It appeared that in the B systems (enriched with ammonia salts) nitrogen in this form was removed almost in 100%, while in three cases the final concentrations of nitrates exceeded the initial concentrations. Probably N-NH_4 is a more preferable source of nitrogen than N-NO_3 for algae. At algal blooms which deteriorate the light conditions, ammonia salts are the main source of nitrogen [15]. In experiment 1, apart from ammonia salts, nitrates were also removed, though to lower degree. In the B series the concentration of ammonia nitrogen was the lowest one. Assuming that ammonia salts were the main source of nitrogen, it seems probable that their amount was sufficient. From the experiments it followed that nitrates were better uptaken by algae when initial concentrations of these compounds were low. Thus it may be inferred that the amount of energy in the system suffices to remove the nitrates uptaken by algae. It is known that in all organic compounds nitrogen appears in reduced form, regardless of the form it was uptaken. High concentrations of total phosphorus and orthophosphates in the first days of the experiment 4, stated in the system A, may be due to disintegration of the algal cells or to insufficient rinsing of the algae culture used for inocculation.

D. magna which is sometimes used to remove algae [3, 4] could also be the nutritive basis for fish.

L. minor is an excellent fodder. It contains far more proteins and less fibre than red trefoil, corn or lucerne [1]. It could be used as the addition to fodder or the food for ducks.

5. CONCLUSIONS

The following conclusions are drawn on the basis of experiments performed:

1. High degree of orthophosphates removal, which within 10-15 days may reach 100%, was obtained on the drainage water.
2. In the systems with added nutrients (B) the degree of total phosphorus removal reached 86% after 12 days of the experiment.
3. The removal of orthophosphates increased with theoretical retention time. A higher degree of removal achieved in shorter time was obtained in the systems with high initial concentrations of nutrients (B).
4. In the systems loaded with nutrients the degree of total nitrogen removal was high.
5. The percentage of ammonia nitrogen removal was higher, in general, in the systems with high initial concentrations of this compound.
6. In the systems without nutrients (except for experiment 3) the removal of nitrates was higher.
7. Large number of psychrophilic bacteria was connected with large number of algae cells.
8. In each system the number of algae in aquarium II was usually larger than in aquarium I. Thus the optimal conditions of the development were established in aquarium II.
9. Higher increase of algae (except for experiment 1), *D. magna*, and *L. minor* occurred in the B systems.
10. High number of algae affected the increment of *D. magna* individuals (experiment 2 was characterized by small numbers of algae and low increase of *D. magna*, and experiment 3 by large number of algae and high increase of *D. magna*).
11. Low increase in algae and daphnia accompanied by high increase of *L. minor* could indicate that inorganic nitrogen and phosphorus not uptaken by algae were removed by plants.
12. Further investigation should be concentrated on the effects of staging the process ponds on the efficiency of nutrients removal.

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USUWANIE ZWIĄZKÓW BIOGENNYCH W STAWACH BAKTERYJNO-GLONOWYCH — DOŚWIADCZENIA NA SKALĘ LABORATORYJNĄ

Badania miały na celu określenie stopnia usuwania związków biogennych z wód drenażowych w stawach bakteryjno-glonowych. Doświadczenia prowadzono w dwóch seriach: w jednej wykorzystywano wodę drenażową pobieraną z rowu odwadniającego, w drugiej wzbogacano tę wodę dodatkowo związkami biogennymi.

Glony z dwóch pierwszych zbiorników układu badawczego były usuwane w sposób naturalny — były pokarmem *Daphnia magna* wprowadzonych do zbiornika 3. *Lemna minor*, występująca w ostatnim zbiorniku, miała usuwać nie wykorzystane przez glony związki azotu i fosforu.

W obu seriach doświadczenia stwierdzono wysoki (dochodzący do 100%) stopień usuwania ortofosforanów. Procent usuwania tej formy fosforu zwiększał się wraz z teoretycznym czasem przepływu wody drenażowej. W badaniach, wykorzystujących wodę drenażową wzbogaconą solami biogennymi, uzyskano usunięcie fosforu ogólnego dochodzące do 86%. Dla tej serii badań uzyskiwano także wysoki stopień usunięcia azotu ogólnego. Procent usunięcia azotu amonowego był na ogół wyższy dla wody o większym

ego stężeniu początkowym. W przypadku azotanów procent ten był wyższy dla wody bez dodatku soli pokarmowych.

Większy przyrost liczby glonów, rozwielitek i rzęsy stwierdzono w wodzie drenażowej wzbogaconej biogenami. Zaobserwowano także, że przyrost liczby *L. minor* był odwrotnie proporcjonalny do przyrostu liczby glonów.

DIE BESEITIGUNG VON NÄHRSTOFFEN IN KOMBINIERTEN BAKTERIEN-ALGEN-TEICHEN — VERSUCHE IM LABORMAẞSTAB

Die Versuche hatten zum Ziel, den Abbaugrad von biogenen Stoffen die im Abfluß einer Drainage enthalten sind, in kombinierten Bakterien-Algen-Teichen zu untersuchen. In einer Versuchsreihe wurde nur das aus dem Hauptgraben abfliessende Drainagewasser genutzt, im Parallelversuch dasselbe Wasser künstlich angereichert mit Nährstoffen.

Algen aus den zwei ersten Becken wurden in natürlicher Weise entfernt — sie dienten nämlich als Nahrung für *Daphnia magna* im dritten Becken. Das letzte Becken war mit *Lemna minor* besetzt und dies sollte den Entzug der Restmengen von N und P gewährleisten.

In beiden Versuchsreihen konnten Ortophosphate fast vollkommen entzogen werden; der Abbaugrad dieser Phosphorform wuchs parallel zur Verweilzeit. Im angereicherten Wasser betrug die maximale Bindung des allgemeinen Phosphors 86%. Die Bindungsrate des Stickstoffs war auch hoch. Die Abbaurate von Ammoniakstickstoff war im allgemeinen höher dann, wenn seine Anfangskonzentration größer war. Nitrate wurden in nicht angereicherten Proben besser abgebaut. Bessere Wachstumsverhältnisse für Algen, für die Wasserflöhen und Wasserlinse lagen im angereicherten Wasser vor. Der Zuwachs von *L. minor* verhält sich reziprok zum Zuwachs der Algen.

УДАЛЕНИЕ БИОГЕННЫХ СОЕДИНЕНИЙ В БАКТЕРИАЛЬНО-ВОДОРОСЛЕВЫХ ПРУДАХ (ИСПЫТАНИЯ В ЛАБОРАТОРНОМ МАСШТАБЕ)

Исследования имели своей целью определение степени удаления биогенных соединений из дренажных вод в бактериально-водорослевых прудах. Опыты проводились в двух сериях: в одной использовалась дренажная вода, поступающая из водоотводного канала, в другой серии эта вода дополнительно обогащалась биогенными соединениями.

Водоросли из двух первых водоёмов исследуемой системы удалялись естественным путём — были кормом дафний (*Daphnia magna*) введённых в водоём 3. Маленькая ряска (*Lemna minor*), выступающая в последнем водоёме, должна была удалять не использованные водорослями азотистые и фосфористые соединения.

В обеих сериях опыта была выявлена высокая, доходящая до 100%, степень удаления ортофосфатов. Процент удаления этой формы фосфора увеличился с увеличением теоретического времени расхода дреножной воды. В испытаниях, использующих дренажную воду, обогащаемую биогенными солями, было достигнуто удаление общего фосфора, доходящего до 86%. Для этой серии испытаний получили также высокую степнь удаления общего азота. Процент удаления аммиачного азота был, в общем, выше для воды с более высокой начальной концентрацией. В случае нитратов этот процент был выше для воды без добавки кормовых солей.

Большее возрастание числа водорослей, дафний и ряски было выявлено в дренажной воде, обогащённой биогенами. Было отмечено также, что возрастание числа маленькой ряски было обратно пропорциональным возрастанию числа водорослей.