Future Treatment System of Radioactive Wastewater in Fukushima using Indigenous Algae

-- For Protecting our Oceans from the Pollution --

Stockholm Junior Water Prize Entry 2021

Fukushima Seikei High School

Team S. C.

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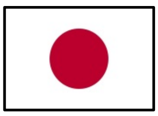
JAPAN



(a) Abstract

The accident at the Fukushima Daiichi nuclear power plant 10 years ago still caused evacuation of 36 thousand people and generated a large amount of radioactively contaminated water that possibly cause adverse impact on marine ecosystem. My seniors conducted a survey of microorganisms in the vicinity of my high school, and found a green alga *Closterium moniliferum*, submerged plant, *Chara brunii,* and a cyanobacterium *Nostoc commune*. I took over the research from the predecessors and have attempted to develop a treatment system using these indigenous plants for the treatment of radioactively contaminated water, with the final goal of proposing a novel alternative to a current approach: discharge of treated water into the ocean. To achieve the final goal, the objectives of this study were: (1) to investigate the influence of Ca^{2+}, a coexisting divalent cation, on the crystal growth of $SrCO_3$ on the surface of *C. brunii.* (2) to examine the uptake of Sr by *C. moniliferum* with and without a photosynthesis inhibitor at different Sr concentrations, and (3) to investigate the influence of irradiation time and the amount of *N. commune* on the evaporation of water. Experimental data showed that $CaCO_3$ crystals adsorbed on the cell surface did not play a role as a nucleus for $SrCO_3$ formation, but crystals were found on the cell surface when the solution contained dissolved Ca and Sr simultaneously. It was also found that the amount of Sr in the cell was larger (0.092 ng/cell) in the case of lower $SrCl_2$aq (0.10 mM) without a photosynthesis inhibitor, indicating that photosynthesis is involved in Sr absorption. In addition, the water evaporation was found to be enhanced by the presence of *N. commune* and continuous irradiation of blue LED. Based on these research results, we propose a polluted water treatment system combining these three aquatic plants.

(b) Contents

(c) Abbreviation

SEM-EDX: Scanning Electron Microscope – Energy Dispersive X-ray

DCMU: 3-(3,4-dichlorophenyl)-1,1-dimethylurea

ALPS: Advanced Liquid Processing System

(d) Acknowledgements

I highly appreciate the support from Profs. Kenji Nanba, Daisuke Sugimori, Hironori Ohashi, and Motoko Takase of Fukushima University for SEM-EDX analysis. I also appreciate the supervision by Prof. Shuji Otani of Shimane University for culturing *C. moniliferum*, Prof. Nobuhiko Sakurai of Nagoya City University for the analysis of Sr using an atomic absorption spectrophotometer, Dr. Mikio Tsuzuki of Tokyo Pharmaceutical University for the advice about a photosynthesize inhibitor, DCMU. I also thank the support and guidance from Makoto Kubonouchi of Environment Daizen Co., Ltd., Mr. Hiroyuki Takenaka of Micro Algae Corporation, and Leave a Nest Co., Ltd., Ebara Corp. And special thanks go to Dr. Hiroshi Yamamoto of National Institute for Environmental Studies, Assoc. Prof. Tasuma Suzuki of Yamaguchi University and Mr. Keisuke Tsukamoto of Japan River Association. I cannot complete this project without their support. Finally, I appreciate Mr. Go Yamamoto, Dr. Lillian Yoneda, Ms. Mizuki Endo, Mr. Keisuke Nemoto of Fukushima Seikei Highschool, who provided me with advice for preparing this paper.

We would like to take this opportunity to express our sincere gratitude for all of their support and guidance.

(e) Self-introduction

Miki KAMIMURA

I am a third-year student of Fukushima Seikei High School. I have been conducting research, taking over from my predecessors. We have worked about ten years for revival of Fukushima.

In the future, I would like to find a method for mass cultivation of *Nostoc commune,* because a large amount of *N. commune* is needed for the treatment of contaminated water.

1.Background and motivation

Fig. 1 Satellite image of storage tanks near Fukushima Daiichi Nuclear Power Plant (Google Earth**).**

It has been 10 years since the tsunami caused by Great East Japan Earthquake hit Fukushima Daiichi Nuclear Plant to cause the disaster including nuclear meltdowns and three hydrogen explosions. In addition to the over 1600 deaths directly by the earthquake and tsunami in Fukushima Prefecture only, nearly 36 thousand people had to evacuate from the vicinity of the nuclear power plant, approximately 140 tons of contaminated water per day have been generated from rainwater/groundwater. Over 1000 tanks constructed near the plant will become completely full by the spring of 2023 **(Fig. 1)**. On April 13, 2021, the government officially announced to discharge contaminated water into the sea after treatment in 2023, which might cause potential effect on coastal ecosystem and surely cause reputational damage on fisheries.

According to Tokyo Electric Power Co. (TEPCO)[1)] who has been managing the power plant, 337100 m^3 (29%) is the treated water by Advanced Liquid Processing System (ALPS) under the regulatory standard while still 832900 m^3 (71%) is "water in process of treatment" which does not meet the regulatory standards for safety. The major nuclides contained in the water were ^{137}Cs (Cesium-137), ^{134}Cs (Cesium-134), ^{60}Co (Cobalt-60), ^{125}Sb (Antimony-125), ^{106}Ru (Ruthenium-106), ^{90}Sr (Strontium-90), ^{129}I (Iodine-129), and ^{3}H (or T: Tritium). Among them, ^{90}Sr (half-life of 29 years) and two of Cesium isotopes (half-life of ^{137}Cs and ^{134}Cs is 30 and 2.1 years, respectively) are the major concerns in "water in process of treatment" while relatively low level of tritium (half-life of 12 years) is the major concern in the ALPS treated water.

10 years ago, just after the earthquake and nuclear power plant accidents, my seniors started

a microbiology survey at Chaya-marsh near my high school with a thought that microorganisms might be susceptible to radiation. One of the microorganisms found in the survey was *Closterium moniliferum* **(Fig. 2a)**, a unicellular green alga. After literature review regarding this alga, they found a literature[2)] describing about separation and fixing mechanisms of two alkaline earth metals, Ba and Sr, in the terminal vacuole part of the alga, and started a research project on the possibility of recovering ^{90}Sr in polluted water using the alga. Another microorganism found during the survey was *Chara braunii* **(Fig 2b)**, one of the streptophyte algae. The alga has been reported to adsorb Ca^{2+}, the same alkaline earth metal as Sr^{2+}, outside the cell wall as $CaCO_3$[3)]. Therefore, this alga was chosen and investigated in this study to remove Sr^{2+} from aqueous solutions as $SrCO_3$. More recently, our research group focused on one of the terrestrial cyanobacteria, the stinging *Nostoc commune* (**Fig. 1c)**. We found a literature[4)] showing that *N. commune* was able to absorb and accumulate Sr and Cs in both cells and extracellular substrates. In addition, this cyanobacterium can absorb water 30 times as heavy as its own weight. Therefore, we thought that we can utilize this unique property of this bacteria to treat tritium that remains at the site of the nuclear power plant.

(a) **(b)** **(c)**

Fig. 2 Pictures of **(a)** *Closterium moniliferum* (**b)** *Chara braunii* and (**c)** *Nostoc commune*

Based on above-mentioned thoughts, by combining these three algal species, we proposed future treatment system for radioactively contaminated water in Fukushima Daiichi Nuclear Power Plant (**Fig. 3)**. In the first stage, our seniors have already observed the phenomenon of adsorption of Sr by the *C. bruniiin*, so I focused my research efforts to elucidate conditions for more efficient Sr adsorption. In the second stage, red LED had already been found to be effective for the absorption of Sr at low concentrations by *C. moniliferum*. Therefore, in this study, the amount of Sr absorbed into the cells by *C. moniliferum* was quantified to judge whether photosynthesis was involved in the absorption of Sr. In the third stage, we intended to utilize the ability of the *N. commune* to treat Sr and Cs that could not be processed in the first and second stages. In addition, we thought that we could use the ability of the dried *N. commune* to absorb 30 times its own weight of water to reduce large amount of tritiated water in the tanks. Therefore, I investigated the influence of the amount of *N. commune* and irradiation conditions to maximize the decrease of water. Although 10 years have passed since the nuclear accident, some countries have restrictions on import for radioactive materials and require certificates. I believe that radioactive materials released into the environment should be minimized in order to dispel this harmful reputation.

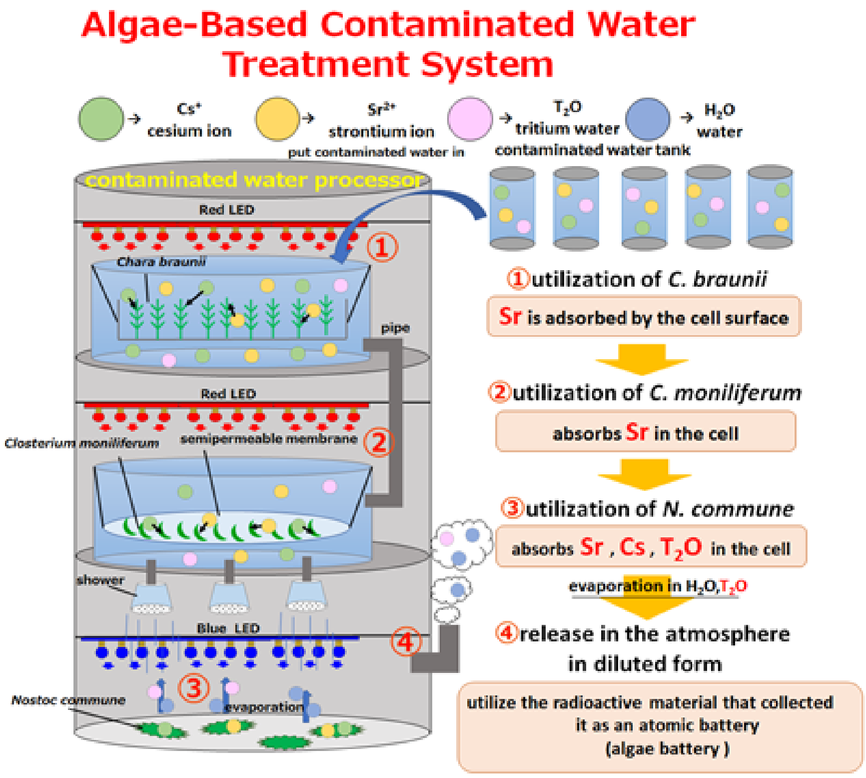


Fig. 3 Proposed future treatment system for radioactively contaminated water in Fukushima Daiichi Nuclear Power Plant.

2. Objectives

The specific objectives of this study were as follows:

(1) To evaluate the favorable conditions for the efficient removal of Sr by a streptophyte alga, *C. braunii*, the influence of Ca^{2+}, a coexisting divalent cation, on the crystal growth of $SrCO_3$ on the surface of *C. brunii*. was investigated.

(2) To better characterize the removal of Sr by a unicellular green alga *C. moniliferum*, Sr absorbed into the cells was quantified with and without a photosynthesis inhibitor and different Sr concentrations. (3) To better characterize the mechanism of water loss by a terrestrial cyanobacteria, *N. commune*, the effects of changing the initial dry weight of the *N. commune* and the irradiation time were investigated.

3. Test methods and results

3.1 Characterization of Sr adsorption by a streptophyte alga, *C. braunii*

On the basis of $CaCO_3$ formation observed for Char sp. including by *C. braunii*[3], Sr adsorption based on the similar mechanism (i.e., $SrCO_3$ formation) was expected because both are alkaline earth metals. *C. braunii* is known to use HCO_3^- to perform photosynthesis and excrete OH^- from a specific site ($HCO_3^- \rightarrow CO_2 + OH^-$), which makes the surrounding pH to be slightly basic at pH 7-9 and forms alkaline bands on the cell surface. In the alkaline band, the concentration of carbonate ions (CO_3^{2-}) increases and as a result, practically insoluble $SrCO_3$ is precipitated near the cell surface ($Sr^{2+} + CO_3^{2-} \rightarrow SrCO_3$). Our research group had compared the formation of alkaline bands on the cell surface of *C. braunii* using red, blue, and green LEDs and find that the alkali band was best efficiently formed by red LED with using the tip part of *C. braunii.*

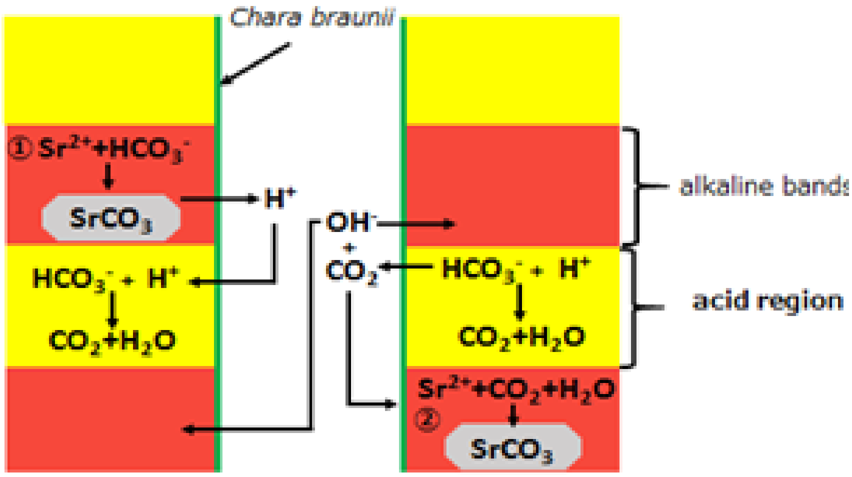


Fig. 4 Expected mechanism of a streptophyte alga *C. braunii* for $SrCO_3$ formation

However, when *C. braunii* was added to agar medium containing $SrCl_2$, even though we use red LED light, the apparent $SrCO_3$ formation was not observed. Therefore, I changed my strategy and decided to form $CaCO_3$ crystals first on the cell surface, and then $SrCl_2$ was added into the whole agar to observe the growth of the crystals. In the research by predecessors, they found that white crystals were adsorbed on the surface of *C. braunii* in the culture medium (10 mM $SrCl_2$, 10 mM $CaCl_2$, 0.1wt% Hyponex) and observed under natural light. In this study, I focused on the influence of Ca/Sr concentration ratio to investigate the optimized condition for crystal formation and potential Sr removal from water.

(1) Methods

Aqueous solutions containing *C. braunii* were irradiated with red LED (640 nm, irradiation distance: 10 cm, photon flux 16 $\mu molm^{-2}s^{-1}$, 20 °C±3°C, 12 h light on: 12 h light off) without stirring. Two different culture media, samples A (10 mM $CaCl_2$, 10 mM $SrCl_2$, 2.0 mM $NaHCO_3$) and B (0.1 mM $CaCl_2$, 10 mM $SrCl_2$, 2.0 mM $NaHCO_3$) were prepared. The most apical node of the spider was cut out and added into the polyethylene bag containing the culture media. The samples were observed using a stereomicroscope.

(2) Results and discussion

In sample A **(Fig. 5a)**, crystal adsorption was observed from the first day as shown in **Fig. 5b**. On the 13th day, crystal adsorption covering the entire cell surface was observed as shown in **Figs. 5c** and **5d**. However, no crystal formation was observed in sample B. In addition, when comparing the cell condition after two weeks, the cell condition of sample A was good while the cell condition of sample B was deteriorated. From the results in **Table 1**, it was clear that the *C. braunii* adsorbed crystals on the cell surface under the environment where the concentrations of Ca and Sr were comparable. This result is consistent with the previous study conducted by my predecessors. The Ca concentration of 10 mM was found to be effective to maintain a good cell condition while 0.1 mM was not.

Table 1 Summary of *C. braunii* study using two different media.

	Crystal adsorption	Cells condition
Sample A (Sr: 10 mM, Ca: 10 mM)	YES	Good
Sample B (Sr: 10 mM, Ca: 0.1 mM)	NO	Deteriorated

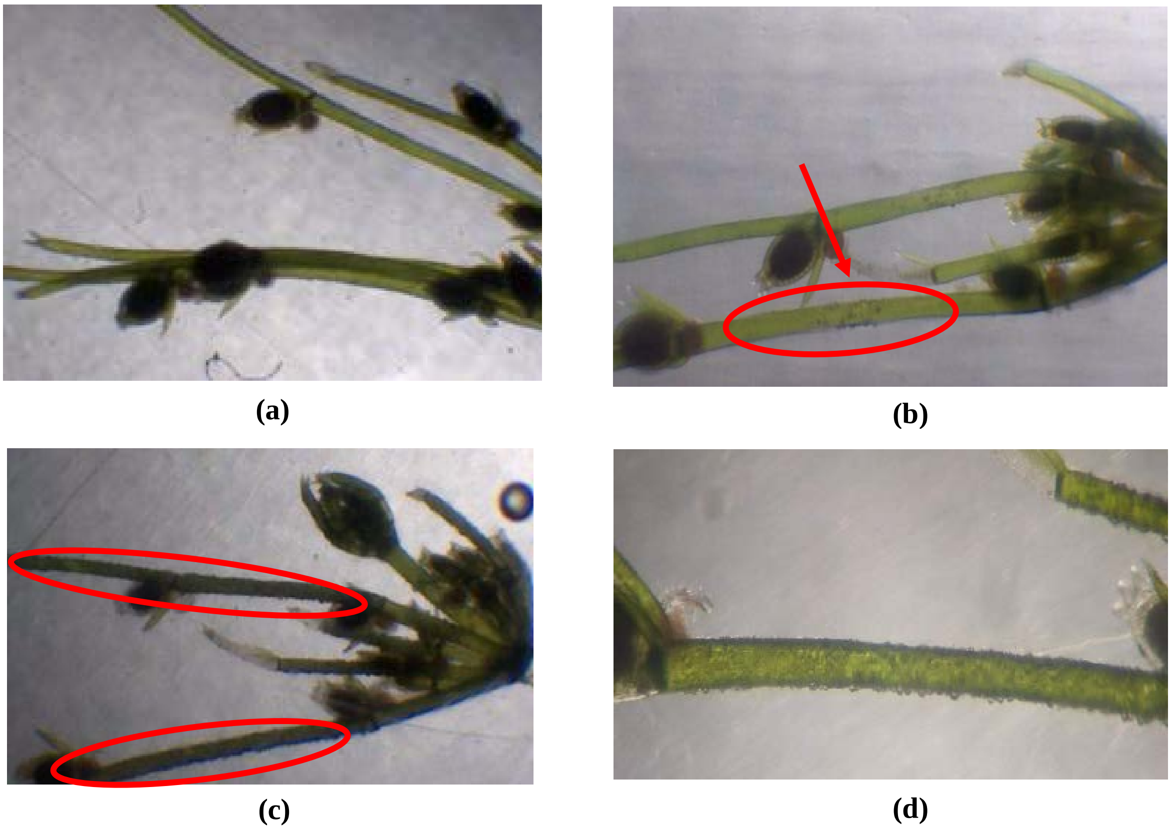


Fig. 5 Images of *C. braunii* and formation of crystals **(a)** immediately after being placed into liquid medium, **(b)** first day in liquid medium (Crystals are in the red circle), **(c)** on the 13th day in liquid medium (Crystals are in the red circles), and **(d)** Enlarged image of the bottom red circle of Fig. 5c.

3.2 Characterization of Sr removal by a green alga, *C. moniliferum*

3.2.1 Comparison of the amount of Sr absorbed into the cells of *C. moniliferum* at different Sr concentrations

(1) Methods

Schematic diagram of experimental system is shown in **Fig. 6**. This experiment was performed using red LED (640 nm) because my preliminary study showed that the LED provided the most efficient Sr absorption. Irradiation distance was set at 37 cm (light quantum amount of 7.5 $\mu m^{-2}s^{-1}$) and exposed to $SrCl_2$ solution (10 mM) for 48 h. In order to investigate the influence of Sr concentration, *C. moniliferum* was also exposed to 0.10mM of $SrCl_2$ for 48 h. Sr concentration in the cells were measured based on the procedure used in the literature[5)] using a graphite furnace atomic absorption analyzer (Shimadzu AA-6300).

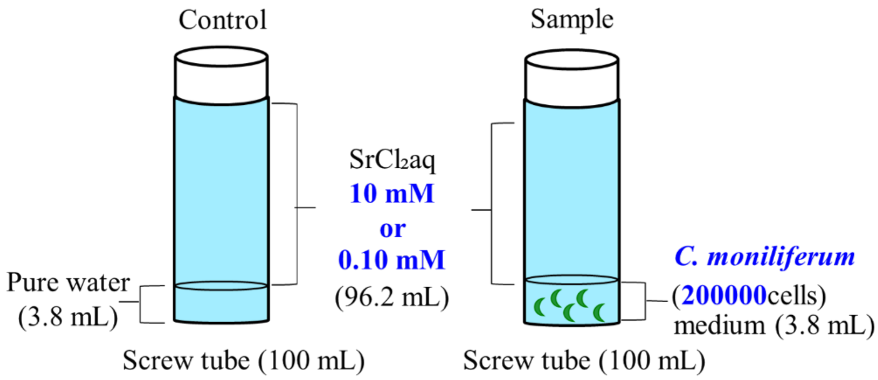


Fig. 6 Schematic diagram of experimental system used to investigate Sr absorption by *C. moniferum* at different Sr concentrations

(2) Results and discussion

Table 2 Sr concentration in *C. moniliferum* at different concentrations of $SrCl_2$

$SrCl_2$ Concentration	Concentration (ng/cell)	Recovery
10 mM	0.24	0.059%
0.10 mM	0.092	2.1%

As shown in **Table 2**, the amount of Sr absorbed per cell was quantified as 0.092 and 0.24 ng/cell at $SrCl_2$ of 0.10 and 10 mM, respectively. The Sr recovery from the solution was 2.1% and 0.059% for $SrCl_2$ concentration of 0.10 and 10 mM, respectively. Light microscopy was also used to observe the cell status of *C. moniliferum* before and after being added to $SrCl_2$ solution **(Fig. 7).** Both samples showed granules in terminal vacuoles of *C. moniliferum* that did not stain with iodine solution **(Figs. 7b and 7d)**. Previously, the predecessors of our research team had confirmed by light microscopy that white granules increased in the terminal vacuoles of *C. moniliferum* exposed to $SrCl_2$, suggesting that *C. moniliferum* absorbs Sr into the cells. The higher recovery of Sr in solution at lower $SrCl_2$ concentration (0.10 mM) than a the higher $SrCl_2$ concentration (10 mM) may be due to the better cell condition of *C. moniliferum* exposed to 0.10 mM than that exposed to 10 mM, potentially toxic to this unicellular green alga.

In addition, the relatively high recovery of Sr (2.1%) in low concentration (0.10 mM) of $SrCl_2$ suggests the possibility of selective absorbing Sr not only in the highly contaminated water but also in the treated water with relatively low concentration of Sr. Therefore, in the future contaminated water treatment system proposed in this study (**Fig. 3**), it is reasonable to install the *C. moniliferum* system

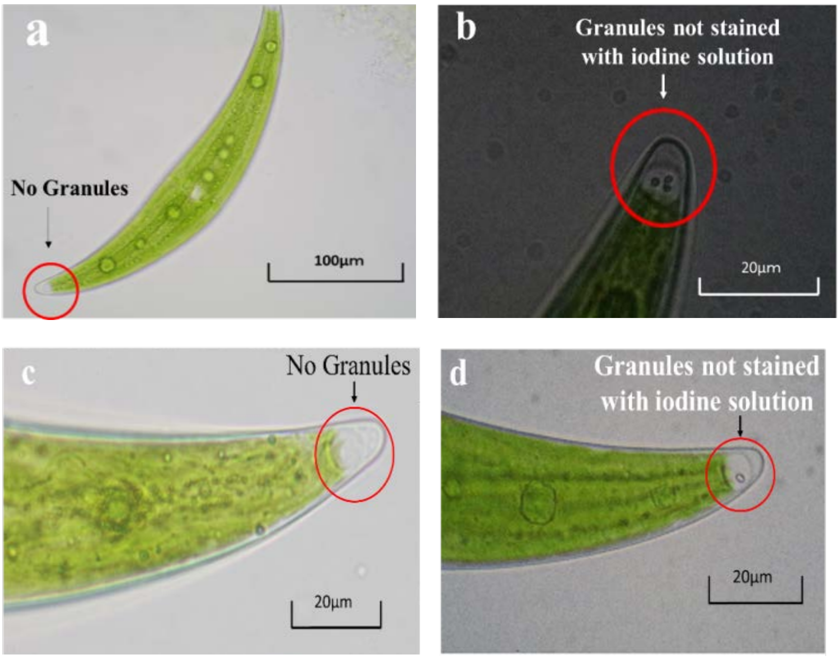


Fig. 7 Images of terminal vacuoles of *C. moniferum* (a) before exposing to 10 mM $SrCl_2$, (b) after exposing to 10 mM $SrCl_2$, (c) before exposing to 0.1 mM $SrCl_2$, and (d) after exposing to 0.1 mM $SrCl_2$.

after the removal of Sr by *C. braunii*.

3.2.2 SEM-EDX observation of *C. moniliferum* with and without photosynthesis inhibitor (DCMU)

(1) Methods

In order to conclude whether photosynthesis is critically involved in Sr absorption by the green alga, *C. moniliferum* cells were inoculated into CA medium A (with neither $SrCl_2$ nor a photosynthesis inhibitor, diuron (DCMU: 3-(3,4-dichlorophenyl)-1,1-dimethylurea)), medium B (with only $SrCl_2$ (0.10 mM) without DCMU), and medium C (with both $SrCl_2$ (0.10 mM) and DCMU (10 µM)). The screw-cap tubes with three different conditions were irradiated with red LED (640 nm) with the distance of 37 cm (light quantum amount of 7.5 µm $^{-2}$s^{-1}) for 48 h **(Fig. 8)**. After the irradiation, the cells of *C. moniliferum* were dried and analyzed by SEM (Hitachi SU-8000) equipped with EDX (Oxford X-MAX50) to obtain information on morphological structure and elemental composition. Before the analysis using SEM-EDX, the cells of *C. moniliferum* were observed under optical

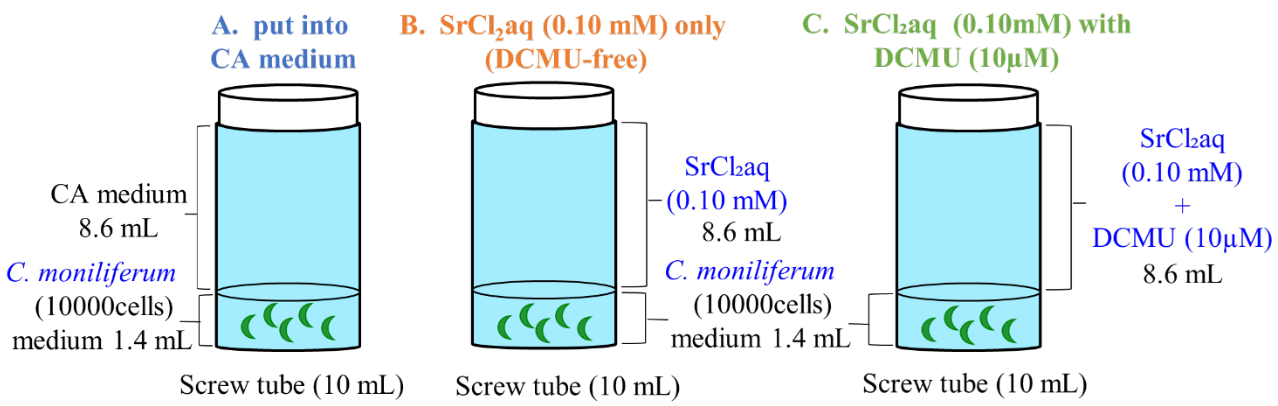


Fig. 8 Three different experimental conditions prepared to examine the relevance of photosynthesis on the absorption of Sr by *C. moniliferum*.

microscope to verify the presence of granules not stained with iodine solution.

(2) Results and discussion

Micrographs of *C. moniliferum* taken by optical and SEM microscopes in the three conditions are shown in **Fig. 9**. In addition, the results of elemental composition analysis using SEM-EDX are shown in **Fig. 10**. Pictures taken with an optical microscope **(Figs. 9a, 9d, and 9g)** revealed white granules in the terminal vacuoles in all samples that were not stained with iodine solution. In the images of SEM-EDX, white crystals were evident in all samples **(Figs. 9c, 9f, and 9i)**, which contained Ba and Sr. Only Ba was detected from the sample sample A **(Figs. 9c, 10a, and 10d)**, while Sr was identified from sample B **(Figs. 9f, 10b, and 10d)** and sample C **(Figs. 9i, 10c, and 10d)**. However, the percentage of Sr was found to be lower in sample C than in sample B **(Fig. 10d)**. These results suggest that the absorption of Sr is strongly related to photosynthesis, since the percentage of Sr in Sample C (with DCMU) was much lower than that Sample B (without DCMU). Surprisingly, relatively high percentage of Ba was detected from the *C. moniliferum* cultured in the CA medium, which does not contain Ba. Unfortunately, I was not able to identify the source of this Ba contamination although I double-checked all the protocol in detail for the possibility of the contamination. Nonetheless, from the comparison of results obtained for Sample B and C, when the green alga *C.*

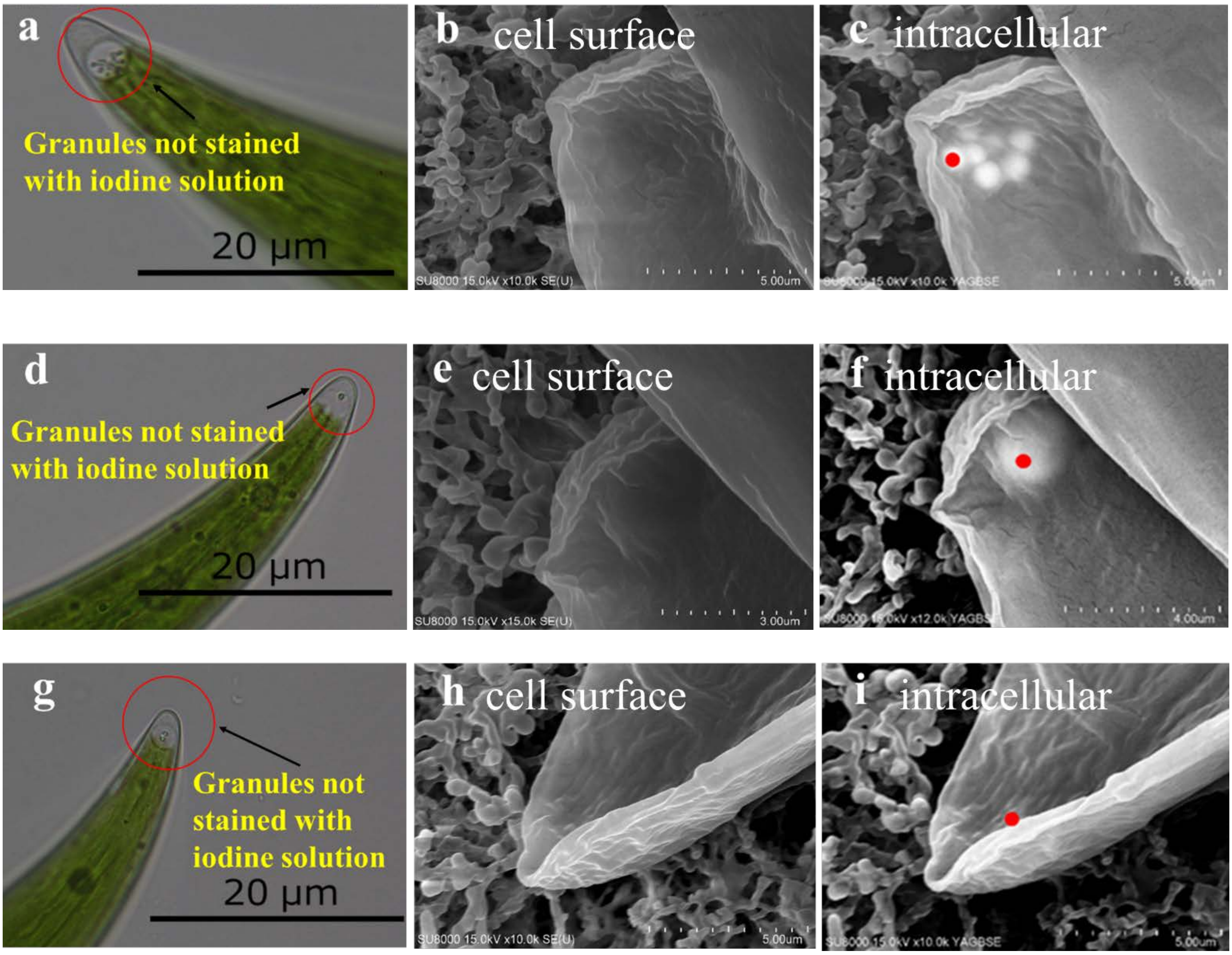


Fig. 9 Micrographs of *C. moniliferum* taken by (a) optical microscope for sample A, (b) SEM-EDX for sample A, (c) SEM-EDX for sample A, (d) optical microscope for sample B, (e) SEM-EDX for sample B, (f) SEM-EDX for sample B, (g) optical microscope for sample C, (h) SEM-EDX for sample C, (i) SEM-EDX for sample C. The elemental composition indicated by red points were further analyzed by EDX. The result is shown in Fig. 10.

moniliferum absorbed Sr from the solution, it is reasonable to conclude Sr in the solution might replace Ba that initially absorbed in *C. moniliferum*, and Ba is released from the terminal vacuole into the solution.

3.3 Enhancement of water decrease by using *N. commune*

In dry condition, the terrestrial cyanobacteria, *N. commune*, often called as "lawn alga",

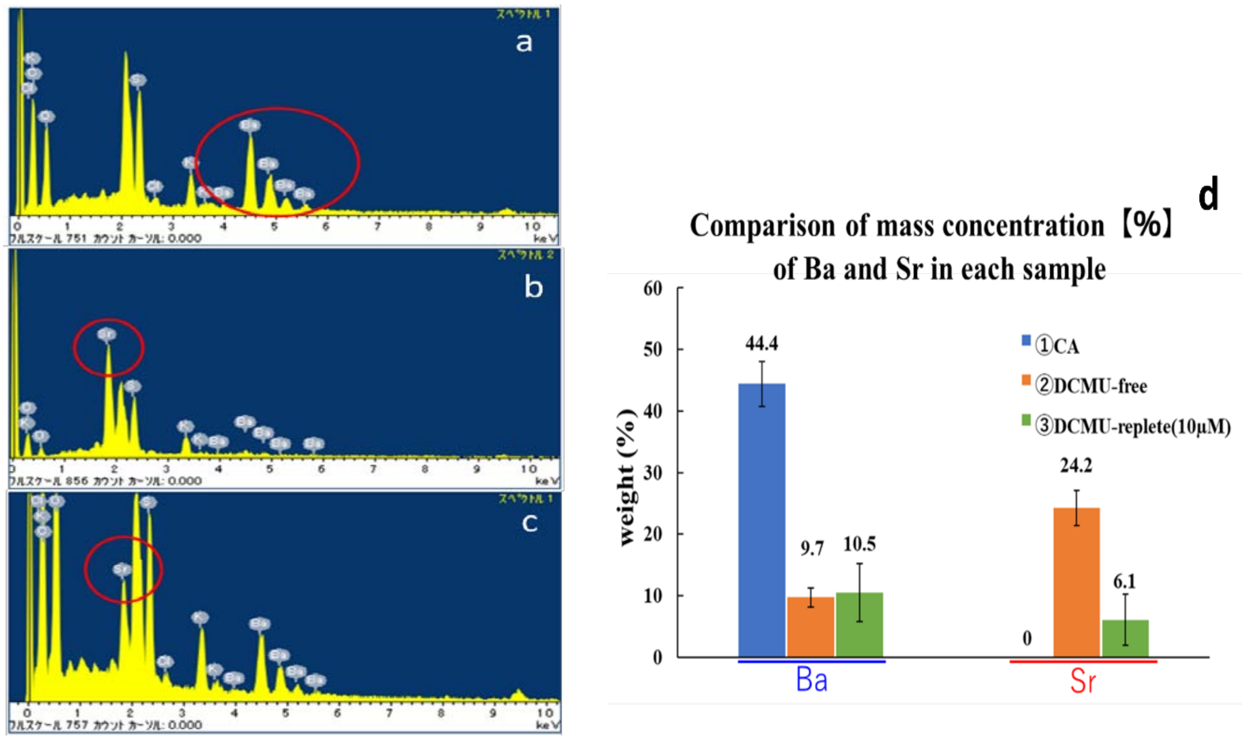


Fig. 9 Results of elemental analysis for (a) sample A (Ba is in red circle), (b) sample B (Sr in red circle), (c) sample C (Sr in red circle), and (d) weight percentage of Ba and Sr.

absorbs 30 times its own weight in water and returns to its original dry state with time if it is in dry conditions. Therefore, we previously placed dry *N. commune* in a container, added water to measure the change in weight to confirm the disappearance of water (i.e., the overall weight decreased as the amount of water visible in the container decreased). We found that the relatively rapid decrease in the container with *N. commune*. My senior and I thought that this *N. commune* could be used to reduce the large amount of partly tritiated water in the site, so we decided to clarify the optimum conditions for the water to be easily disappeared. As a preliminary experiment, we measured the daily weight change of the water-absorbing *N. commune* by irradiating with natural light, blue LED, and red LED, and found that the continuous irradiation with blue LED at a distance of 10 cm resulted in the fastest water decrease.

3.3.1 Enhancement of water decrease by using *N. commune under blue LED irradiation*

(1) Methods

Experimental setup used to investigate the influence of the amount of *N. commune* on daily water loss was shown in **Fig. 10**. 0.1 g of dried *N. commune* and 3 g of an aqueous solution containing 0.1 mM of $SrCl_2$ and CsCl were weighted in each container, and blue LEDs were irradiated 12 h per day. To avoid complete drying, 3 g of the solution was added in each container every day after measuring the weight of the container.

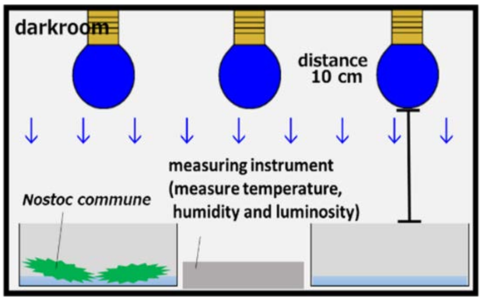


Fig. 10 Experimental setup used to investigate the enhancement of water decrease by using *N. commune* under blue LED irradiation

(2) Results and discussion

Daily water loss (measured by the change in overall weight of each container) during 28 days experiment with and without *N. commune* is shown in **Fig. 11**. Throughout 28 days experiment, the experimental system with *N. commune* showed higher daily water loss than the system without *N. commune*. Specifically, total water loss during 28 days experiment for the system with *N. commune* was 70.7 g, which was approximately 40% higher than for the system without *N. commune* (50.6 g). This experimental data showed that water loss can be enhanced by adding *N. commune*, although responsible mechanisms were unknown at this stage.

3.3.2 Comparison of the amount of water decrease by changing the amount of *N. commune*

(1) Methods

The dried *N. commune* submerged in the water partially floated over the surface. So, the *N.*

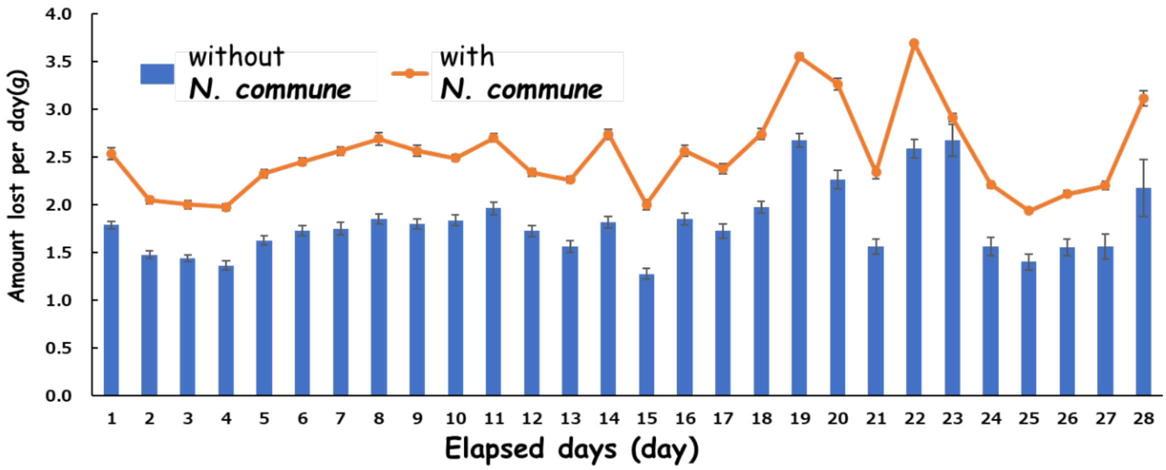


Fig. 11 Water loss during 28 days experiment with and without *N. commune*.

commune samples were prepared with and without a stainless net to avoid the floating of the *N. commune* over the water surface. When *N. commune* was completely submerged in water, it was expected that the amount of water disappeared per day would increase with the increase in the dry weight of the N. commune, and the relationship between the dry weight of the *N. commune* and the amount of water loss was examined. Experimental procedures are described below.

Experimental setup used to investigate the influence of the amount of *N. commune* was shown in **Fig. 12**. I weighed 0.1, 0.2, 0.3, 0.4, and 0.5 g of dried *N. commune* in each container, added 30 g of purified water, and placed a stainless steel net on top of flakes of *N. commune*. Blue LEDs were continuously irradiated at a distance of 10 cm. The weight of the whole container was measured every day for five days. To confirm reprodusability, I prepared four replicates for each amount of dry weight.

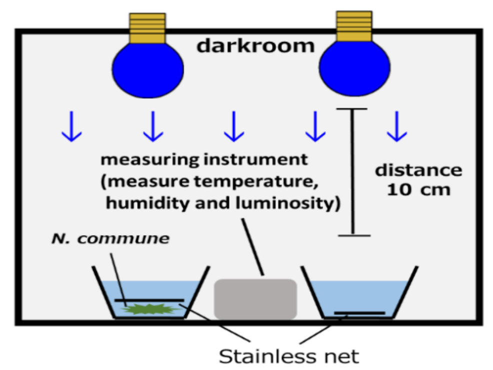


Fig. 12 Experimental setup used to investigate the influence of the amount of *N. commune*

(2) Results and discussion

The average decrease of water in five day with different addition of *N. commune* is shown in **Fig. 13**. As can be seen from **Fig. 13**, the amount of water decrease was the lowest (11.6 g) when *N. commune* was not added. However, the amount of water decrease increased by adding *N. commune*. Specifically, the water decrease of 14.2 g at 0.1 g dry weight of *N. commune* increased to 16.2 g at 0.2 g, but decreased at 0.3, 0.4, and 0.5 g. This result was surprising because higher water decrease was expected for larger amount of dry weight of *N. commune*. However, it was found that the water loss for the 0.5 g was not the highest and no statistically significant difference in water loss on day 5 for 0.3, 0.4, and 0.5 g. Considering blue LED rights were located on top of container, this may be possibly because, in the samples of 0.2 g or more, *N. commune* spread by absorbing water covered the water surface and as a result, *N. commune* in the bottom of the container did not receive sufficient irradiation, and consequently the effects of blue LED (photosynthesis and/or heating) was not proportional to the amount of *N. commune* added in the container.

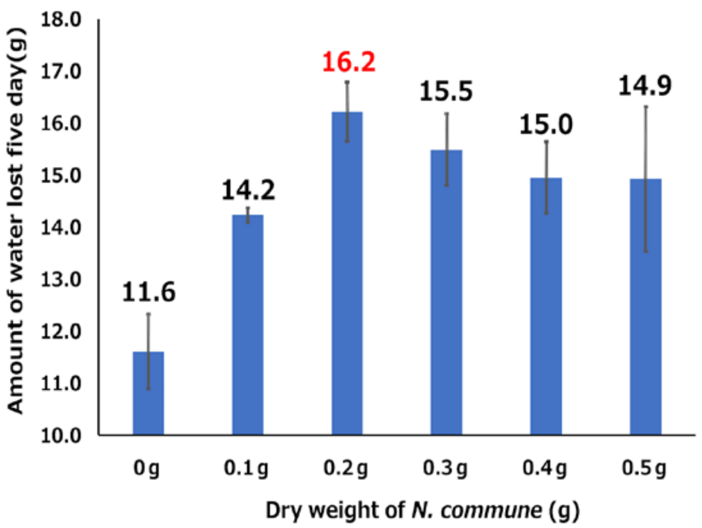


Fig. 13 Relationship between amount of lost in five days and the amount of dry *N. commune* added.

3.3.3 Effect of irradiation time of blue LED on water loss

(1) Methods

I irradiated *N. commune* with blue LED for 12 h and added the mixed solution (0.1 mM $SrCl_2$, 0.1 mM CsCl) every day to confirm the loss of water stably occurs. After 4 weeks, the blue LED was changed from 12 h irradiation per day to 24-hour continuous irradiation, and the weight of the whole container was measured every day for another 28 days, and 3 g of the mixed solution was added every day after the measurement.

(2) Results and discussion

When comparing the samples with and without *N. commune*, the amount of water lost per day was higher in all samples with *N. commune* than without. In addition, the amount of water loss increased nearly three times when the irradiation was changed from 12 h per day to 24 h continuous irradiation **(Fig. 14)**. Therefore, although the reason is not clear, it is reasonable to conclude that continuous irradiation *N. commune* for 24 h enhances the water loss.

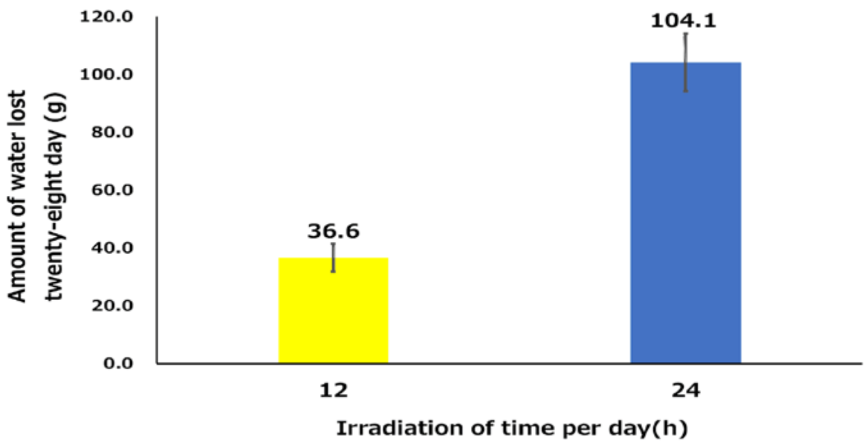


Fig. 14 Difference in the amount of loss by *N. commune* in changing the irradiation time per day.

The color of the *N. commune* gradually changed from the initial dark black to a light brown (**Fig. 15**). Optical microscopy revealed that the cell clusters of spherical cells connected in a bead-like pattern observed in the initial stage gradually broke apart, and sparse spherical bead-like cells were observed (**Fig. 15**). Therefore, it seems the condition of the *N. commune* may not have significant impact on the loss of water. We observed that the amount of water loss increased by adding *N. commune* to the water and irradiating with blue LED, but could not fully elucidate the mechanism of this phenomenon in this study. However, when we compared the water temperature of the samples

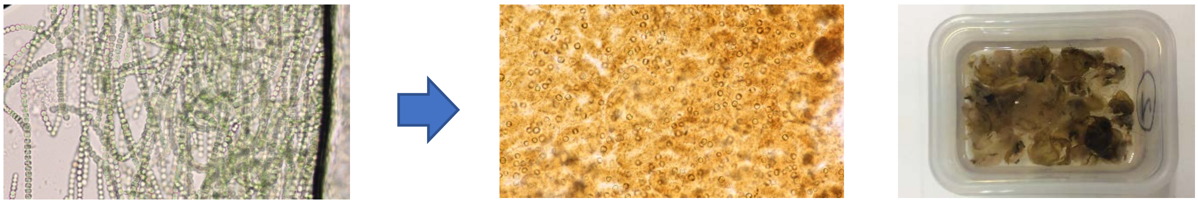


Fig. 15 Pictures of *N. commune* before experiment (left picture) and after 56 days experiment (middle and right pictures)

with and without the presence of the *N. commune*, we found that the water temperature of the sample with the *N. commune* was about 2°C higher than that of the sample without the *N. commune*. It is important to mention that I performed the experiments with black-colored sponges, but I found the water loss was much higher with *N. commune*. Therefore, it is clear that this enhancement of water loss is unique for this organism.

4. Conclusions and future perspectives

Based on the research I took over from predecessors, I would like to reduce the volume of ALPS treated water on the site of the nuclear power plant using our future contaminated water treatment system with various algae.

For a streptophyte alga, *Chara braunii*, used in the first stage of the proposed system (**Fig. 3**), the predecessors had confirmed Sr was adsorbed on the alga, and I confirmed that crystals were produced in the solution containing Ca and Sr. *Chara* was considered to be suitable for use in the first step because of its good cells condition in the presence of Ca and its ability to adsorb Sr even in solutions with high Sr concentrations.

I clarified that photosynthesis of a unicellular green alga, *Closterium moniliferum* was deeply related to Sr absorption in the second stage. I also found that the cell condition of *C. moniliferum* deteriorated in the relatively high Sr concentration, and therefore it was not recommended to use the alga in the first stage. It was considered to be suitable for the second stage, because *C. moniliferum* may selectively absorbs Sr in the environment with low Sr concentration.

I confirmed that continuous irradiation of blue LED was effective as an ideal condition for the disappearance of water in terrestrial cyanobacteria, *Nostoc commune* used in the third stage. In this stage, all of the radioactive material had to be recovered and partly tritiated water had to be reduced, so *N. commune*, which can absorb and decrease water efficiently, was considered to be suitable. However, radioactive materials collected by the *N. commune* must be further managed in a safe manner.

In the final treatment using *N. commune,* the treatment of polluted water by air emission is considered. Of course, this method cannot avoid harmful rumors, but at the Fukushima Daiichi Nuclear Power Plant before the nuclear accident, treated water containing tritium has been discharged into the ocean (about 2.2 trillion Bq per year) and into the air (about 1.5 trillion Bq per year)[6)]. Tritium emits β-ray but the external irradiation may not be at high risk once it is diluted and diffused, and it could be disposed of with minimum risk. It is not an immediate solution, but if there is enough storage space, I think it is important to reduce the volume and attenuate it sufficiently by allowing *N. commune* to absorb it.

Finally, just after the Great East Japan Earthquake in 2011, there were some people who had evacuated from the land they were used to living in due to the nuclear power plant accident, and one of my seniors told me that they had decided to evacuate because their grandparents were living within a 20 km radius of the power plant. When the senior talked to his grandfather about the research in high school, he said, "I'm very happy that young people living in my hometown are working hard to address this problem." After listening to my senior's story, I came to have a stronger passion for this research, thinking that if I who live in the local area, work hard for Fukushima, I can cheer up the people who still suffered from the earthquake.

In addition, for 10 years, our research group have been carrying out this research with the cooperation of many people, including university professors, while devising what we had around us, with the hope of contributing to Fukushima as much as possible. I am proud to be able to carry out this research, and I would like to continue this research with many people involved in it, in order to further develop the research that my seniors have been doing for a long time. It is not possible to solve this problem immediately, but I would like to further improve our contaminated water treatment system, and I would like to continue to do my best to realize the treatment.

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