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Five Years of Rice Cultivation in Paddy Fields for Treated Water from Humus Bioreactor-Type Rural Wastewater Treatment Plants

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Abstract: The treated sewage has a color as well as odor and is difficult to reuse. Physical methods to reduce color with odor are costly and more difficult to reuse. Since the color and odor were reduced by pellet-type bioreactor sewage treatment using humus, rice was cultivated for 3 years. Industrially, 3 years is sufficient to investigate the stability of treatment facilities, but when biological treatment is applied, 5 to 10 years of investigation is required. In addition, in rice cultivation, a similar 5 to 10 years survey is required to investigate the accumulation of low-concentration pollutants. This report is a five-year report and is the result of paddy rice cultivation in a stable wastewater treatment facility. The cultivated rice fully satisfied the edible standards and was able to obtain safe rice, and the effect of reducing fertilizer applied was obtained by using nitrogen and phosphorus from the treated water. In addition, the yield was able to be within the range of the standard yield of 500 kg to 550 kg/1,000 m^2.

Key words: Water reuse, odor reduce, color reduce, bio-reactor, rice production.

1. Introduction

In countries and regions where water shortages are serious, treated water from domestic wastewater is being used for agriculture. On the other hand, in countries with paddy fields with abundant water resources, treated water from domestic wastewater is not used for agriculture. If treated water with a high nitrogen concentration is used for fruit trees and paddy rice with low nitrogen requirement, the leaves will grow overgrown and the stems will grow too much and fall down, so it is avoided to use.

1.1 Use of Treated Water in Paddy Fields, Denitrification, and Biological Conversion of Nitrogen

In addition, paddy rice can only absorb ammonia nitrogen. Nitrogen in treated water is nitrate nitrogen, and plant physiology and nutrition have shown that paddy rice cannot absorb nitrate nitrogen in treated water using tracer elements. However, although research is being conducted in various places to use treated water from domestic wastewater for paddy rice cultivation, as a general rule in textbooks, paddy rice does not grow because nitrogen nitrate cannot absorb nitrogen nutrients, so paddy rice is water from domestic wastewater. Does not grow up. In other words, paddy rice does not grow on nitrate nitrogen nutrition, so if the treated water is discharged into the paddy field without dilution, it can be easily denitrified (roots and straw are separated by a combine and discarded in the paddy field). In paddy fields, the condition of BOD 3 mg/liter or more is sufficiently satisfied for the nitrogen 1 mg/liter required for denitrification. It is important as a place for huge denitrification treatment.

However, in the actual paddy field, the nitrogen component is absorbed by the rice and grows, the vegetative growth continues, and it grows too large and collapses. When the concentration of ammonia nitrogen is high, vegetative growth does not switch to

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reproductive growth. There is a fact that it cannot be harvested because rice ears do not occur.

1.2 As a Textbook Theory, the Consistency between Ammonia Nutrition in Paddy Rice and Nitrate Nitrogen in Treated Water

It is a big problem that completely contradicts the theory of textbooks, but Japanese law even stipulates that when using treated water from an old domestic wastewater treatment facility, it should be diluted 50 times or more. (The drainage standard is more than 10 times looser than the facility of this study). To use treated domestic wastewater in paddy fields, it is stipulated to dilute it with river water or agricultural water. In other words, when the treated water is diluted 50 times or more, it absorbs nitrogen to the extent that it does not cause lodging or ear formation, so the nitrogen in the treated water can be used for paddy rice. It's the exact opposite of textbook theory.

The phenomenon that paddy rice does not fall down or produce spikes by using treated water depends on the absorption of ammonia nitrogen. The mechanism by which nitric acid is converted to ammonia and absorbed by rice during rice cultivation in treated water is unknown in this study.

As a possible phenomenon, nitrate nitrogen is rapidly absorbed by algae growing in paddy fields, so nitrate nitrogen decreases rapidly. It is easy to predict that when algae die, the microorganisms break down the carcasses and release ammonia nitrogen. Furthermore, in recent denitrification treatments, it is easy to speculate that substances metabolized by microorganisms of the ANAMMOX mechanism (= microorganisms that use oxygen nitrate as an energy source) may be reduced to ammonia via nitrite. Below the surface of the paddy soil, it is in a completely reduced state, and anaerobic bacteria that reduce oxidizing substances and use them as energy for growth are effectively active. Nitrosomonas, a nitric acid-reducing bacterium, obtains energy from the oxygen of nitric acid and metabolizes nitrite. The next nitrite-oxidizing bacterium, Nitorobacter, obtains growth energy from the oxygen of nitrite and reduces nitrite to ammonia. In other words, it is easy to assume that there is a reaction in paddy fields that reduces nitric acid to ammonia. It is well known as a microbial reaction of water treatment system related to denitrification from ancient times.

On the other hand, there is a false concept of organic farming as a factor hindering the use of treated water. Unlike animals, plants are characterized by inorganic nutrients that cannot absorb organic matter, but it is an illusion that they absorb organic matter when they are applied. Organic substances applied to soil are decomposed into inorganic substances by the action of microorganisms, and only the same substances as chemical fertilizers are absorbed, but there is an image that substances different from chemical fertilizers are absorbed. Therefore, although the treated sewage has been cleaned, it is feared that some organic matter may be absorbed by plants and taken orally. Unlike pesticides and automobile exhaust gas that arrives on leaves and fruits, plants have a mechanism that allows only inorganic components to be absorbed from the roots. However, many people misunderstand that organic cultivation improves the quality because it takes in organic substances, and they think that using treated water is dangerous and may cause an opposition to the use of treated water.

It was speculated that the problem of color and odor remaining in the treated water in the treatment of domestic wastewater lies in the composition of microorganisms on the biofilm. Therefore, humus in the soil is pelletized and gradually dissolved as a floating carrier to facilitate the supply of soil microorganisms and the growth of microorganisms in water, and to increase the diversity of microorganisms in aerobic and anaerobic tanks. Wastewater treatment was carried out by laying a quality bioreactor. The appearance of higher microscopic metazoans animals in the aerobic tank reduces odor and coloration problems [2, 3].

2. Methods

Please refer to the previous report [1] for the location of the experiment where the wastewater treatment plant is adjacent to the paddy field.

The place where the experiment was conducted is the I treatment plant in A town, Ibaraki prefecture, next to Tokyo (Japan), which is a pure agricultural area with no industry in the vicinity.

Wastewater from the domestic wastewater treatment plant is supplied from five locations (4 m apart) on the short side of the adjacent paddy field, 20 m × 100 m, at 2, 6, 10, 14, and 18 m, and the opposite is true. I made a structure that drains uniformly from the side. Two paddy fields were prepared to test two varieties (Akitakomachi, Koshihikari). The amount of water supplied was measured using a water meter.

Fig. 1 shows a schematic flow of the processing method. The aerobic tank is an intermittent aeration system.

By returning the returned sludge from the settling tank before discharge to the flow rate adjusting tank, it is possible to prevent the generation of odor from the inflow part. In a normal design, the returned sludge is returned to the first settling tank (dust removal), and putrefactive odors and foul odors generated in the inflow part are generated, so that a chemical deodorizing device, a deodorizing device, a dilution diffusion device, etc. are required. By returning the returned sludge with reduced odor to the flow control tank, the entire facility can be deodorized.

The wastewater treated at the facility meets the wastewater standards of BOD (Biological Oxygen Demand) of 5 mg/L or less, nitrogen of 3 mg/L or less, and phosphorus of 1 mg/L or less. However, even with this water quality, nitrogen is excessive for paddy rice, so a fertilizer application design was made in accordance with the physiological phenomenon of paddy rice [1], and repeated cultivation tests were conducted for 5 years.

3. Results and Discussion

3.1 The Amount of Harvest is the Amount of Treated Water Used

There is a misconception that the general public understands agriculture that the higher the yield, the larger the crop. High yields are good, but too high a yield will reduce quality. The appropriate yield varies depending on the crop and cultivation method. In Japanese rice, rice in paddy fields, which has a high yield, is not sweet and has an overripe taste, and the sweetness and chewyness are lost. The appropriate yield was examined by the region and the target yield was established.

The standard yield in this area was about 500 to 550 kg/1,000 m^2, and the 5-year yield met the standard as shown in Table 1. In the second year, Koshihikari

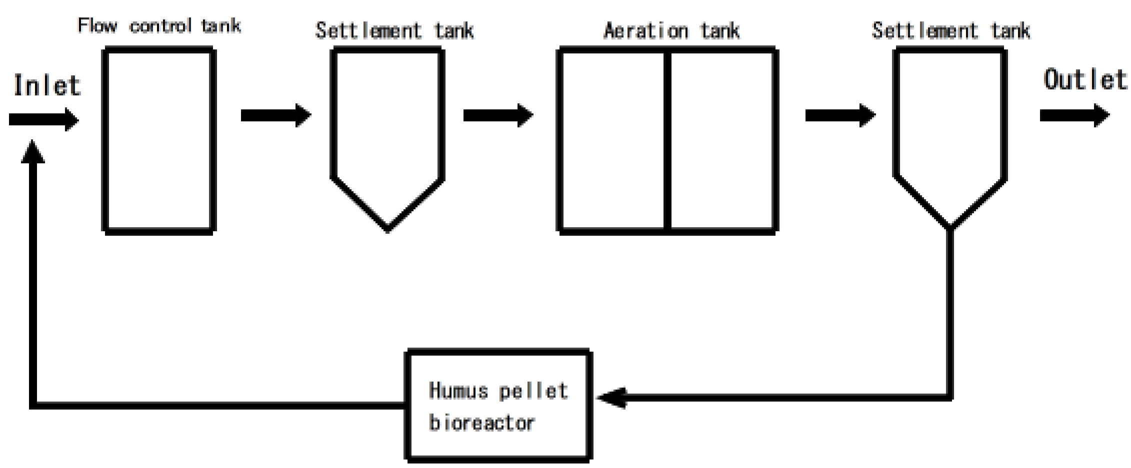

Fig. 1 Schematic diagram of the treatment method and the installation position of the humus pellet bioreactor.

Table 1 Amount of paddy rice harvested and amount of treated water used.

year	Yield (kg/1,000 m^2) Akitakomachi	Amount of water used (m^3)	Yield (kg/1,000 m^2) Koshihikari	Amount of water used (m^3)
1st	520	2,420	540	2,023
2nd	505	2,120	580	2,230
3rd	545	2,585	530	2,145
4th	505	2,355	515	2,290
5th	540	2,620	500	2,365

Table 2 Residual nitrogen concentration at the end of paddy fields (average value of measurement four times a month).

Year	Residual nitrogen concentration at the end of paddy fields (mg/L)							
	Akitakomachi				Koshihikari			
	May	June	July	August	May	June	July	August
1st	0.3	<0.1	<0.1	0.3	0.4	0.1	<0.1	0.5
2nd	0.6	0.2	<0.1	0.6	0.4	<0.1	0.2	0.4
3rd	0.4	<0.1	<0.1	0.2	0.2	0.3	0.2	0.1
4th	0.2	<0.1	<0.1	0.4	0.1	0.2	0.1	0.5
5th	0.5	0.1	0.1	0.3	0.4	<0.1	0.2	0.4

weighs 580 kg, which is a large number, but since there is little rice discarded as immature rice and the weather is blessed, we were able to obtain the quality of first-class rice. When it comes to second-class rice, the price drops by 10% to 15%, and when it falls below that, it becomes a feed for livestock, so ensuring the first-class quality in rice cultivation in Japan is the most important condition for paddy rice cultivation.

3.2 Nitrogen Removal Effect at the End of Paddy Fields

Table 2 shows the nitrogen concentration at the terminal part of the paddy field. The wastewater from this domestic wastewater treatment plant has a nitrogen concentration of 3 mg/L or less. At the end of the paddy field, it has dropped to about 0.1 mg/L, which is close to the measurement limit. The rise in August is the work of draining water from paddy fields to put in a combine of work machines to harvest rice. The work of drying and hardening the surface of paddy fields called soil drying is performed. If the paddy fields are not dried, the work machines will sink into the mud and cannot move. Just like a car gets stuck in the mud, it slips and gets stuck. By drying, the algae that had grown on the surface of the paddy field dried and died.

3.3 Hazardous Metals, Inorganic Elements and Absorption in Japanese Soil

Japanese soil contains more or less trace amounts of harmful metal elements such as cadmium. In paddy fields, by maintaining anaerobic conditions, metals harmful to the human body are adsorbed and retained by soil particles, so in rice cultivation, the transfer of these metals through the roots is minimized. In addition, when the rice ripens, the starch solidifies in the shape of rice. In the process, only starch is bound and cadmium and the like that have entered in a small amount are pushed out to the bran part and have the property of being removed from the white rice part. However, it became necessary to dry the paddy fields before harvesting in order to promote mechanization. Therefore, the soil becomes aerobic and a small amount of cadmium adsorbed on the soil is absorbed from the roots of the rice. Therefore, cadmium is determined to be 400 μg or less per kilogram.

This study was conducted in a place where there is no factory area in the sewage basin and the risk of inflow of heavy metal elements such as cadmium that impair health is extremely low, but various typical elements were analyzed.

Fig. 1 shows the cadmium content in brown rice over a 5-year cultivation period in micrograms per kilogram. As a property of generally harmful inorganic metal elements such as cadmium, cadmium ingested in the body is mainly excreted such as hair. If you continue to take more than the excretion rate, you may have health problems. And 400 μg/kg of brown rice, which is internationally defined, is considered to be safe because it is one tenth of the amount that does not cause damage even if it is ingested for a lifetime. The cadmium content in brown rice in each cultivation season shown in Fig. 1 is 65 to 75 μg/kg for Akitakomachi, and 45 to 55 μg/kg for Koshihikari, which is less than one-fifth of the standard value of rice field. This strongly suggests that the safety can be ensured even if domestic wastewater in rural areas that does not contain factory wastewater is used for paddy rice cultivation. On the other hand, there is a difference of about 20 μg between Akitakomachi and Koshihikari, but Koshihikari, which has a shorter cultivation period and an earlier harvest time, has a shorter soil drying period for introducing the combine than the varietal

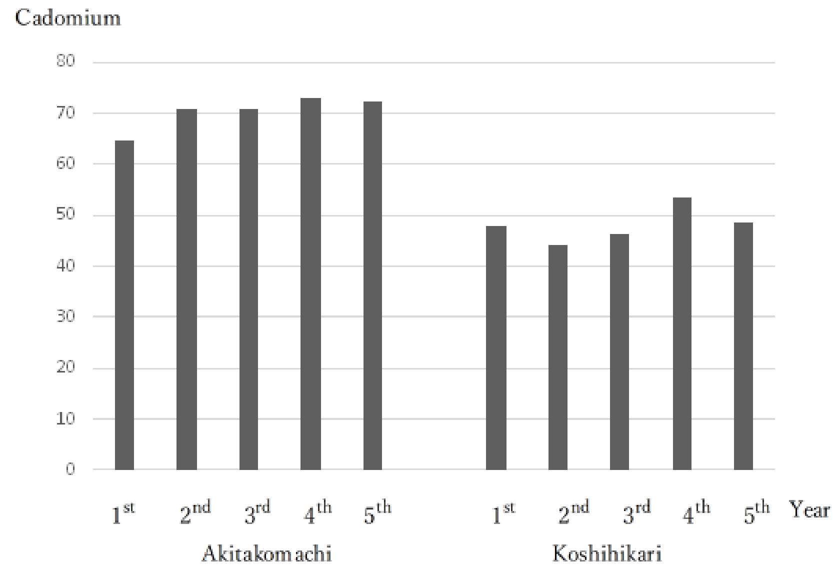

Fig. 1 Cadmium content in brown rice (μg/kg).

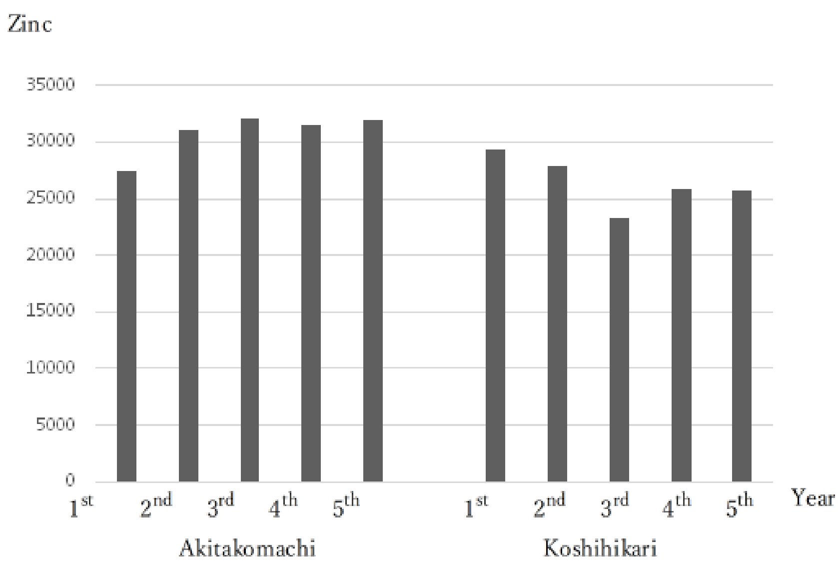

Fig. 2 Zinc content in brown rice (μg/kg).

cause. I imagine that it is the hottest time and that it can be done in a short period of time. In this study, the difference in cadmium absorption is speculative. In general, rice does not have selective absorption of inorganic elements, so the cations released when the soil becomes aerobic and acidified are randomly absorbed from the roots [4, 5].

Fig. 2 shows the zinc content. In general, zinc is an essential trace element for the human body, and is supplemented with supplements. It is a non-harmful heavy metal element required for hormonal balance and bone formation. It is also often used as an indicator of heavy metal pollution in the environment [6, 7]. Since the zinc content was unified in micrograms, the amount of zinc was 27,500 to 32,500 for Akitakomachi and 22,500 to 30,000 for Koshihikari per kilogram of brown rice. It can be converted to 27.5 to 32.5 and 22.5 to 30.0 mg. Zinc is an essential nutrient for maintaining muscle and developing it through training, and adult men are recommended to inoculate 10 mg per day. A good source of zinc is that a rice diet is also effective. It has the same tendency as cadmium and absorbs less Koshihikari. It is speculated that this affected the amount of various trace elements released from the soil of the paddy field that were absorbed and transferred from the roots when they were dried before harvesting in order to introduce the combine harvester.

Rice is about 500 kcal per 150 g of rice. That is, about 4.5 mg is ingested in the brown rice diet, but the amount of white rice in the center is reduced to about one-fifth, and it is difficult to ingest sufficient zinc in the white rice diet because it is reduced to 0.5 mg. On the other hand, in brown rice diet, not only heavy metals but also fat-soluble substances such as pesticides are concentrated in the bran part, so it is necessary to confirm the safety of brown rice by carefully checking the cultivation method by the grower. In addition, in organic farming, which is generally called, organic compounds accumulated in the manure of the original livestock are transferred through the roots of plants, so whether or not organic farming is safe is becoming an important environmental issue. The misconception that organics are safe is collapsing.

3.4 Other Inorganic Nutrition: Copper, Iron, Manganese

The measurement results of copper-iron manganese in brown rice are shown in Figs. 3-5. These three factors are closely related, and copper is required for iron metabolism. Most of the copper acts as a copper

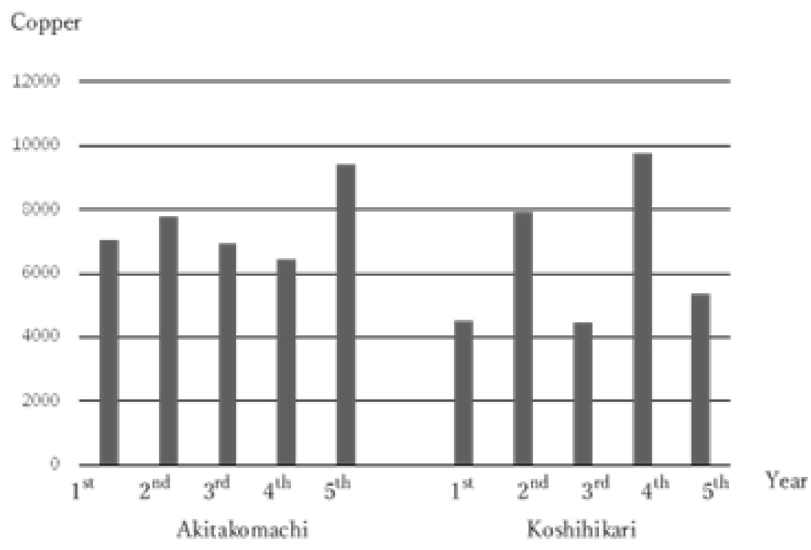

Fig. 3 Copper content in brown rice (μg/kg).

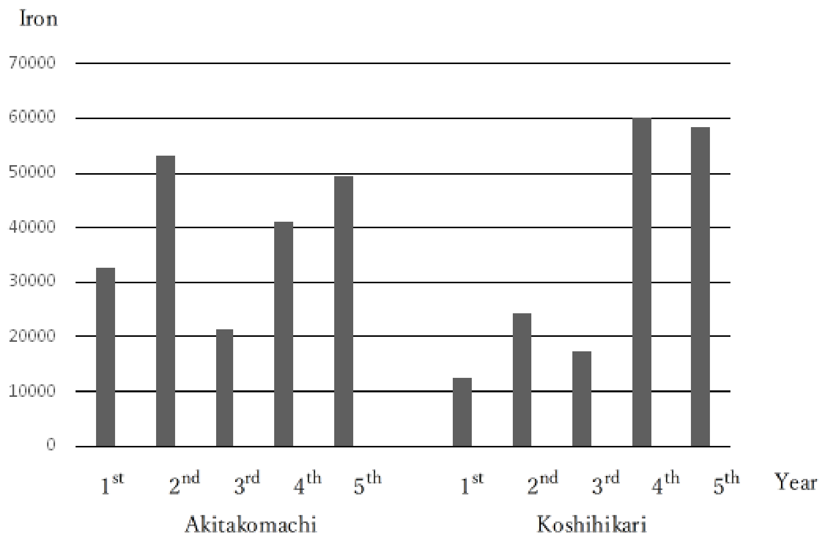

Fig. 4 Iron content in brown rice (μg/kg).

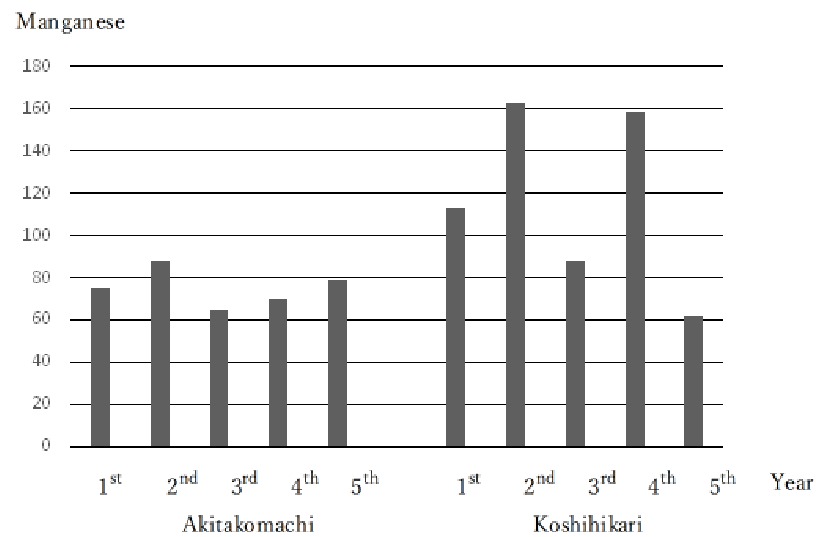

Fig. 5 Manganese content in brown rice (μg/kg).

enzyme bound to a specific protein and acts as a catalyst for various reactions such as oxygen transport, electron transfer, redox, and oxygen addition. Above all, it plays an important role in iron metabolism and transport, removal of active oxygen, and metabolism of neurotransmitters. Manganese is an important mineral for bone growth and is involved in many enzymatic reactions such as glycolipid metabolism, motor function, and skin metabolism. Iron has 3 to 4 g in the body and has two major roles. About 70% of iron is a component of hemoglobin in red blood cells and myoglobin in muscle, and is mainly contained in the protein of red blood cells, hemoglobin, in the form of heme iron. It combines with oxygen and carries oxygen throughout the body [8-13].

In addition, since these metals are excreted from the body even if they are ingested excessively, no standard value has been set. It seems that there was an accident in which 2,000 mg of zinc was accidentally ingested, but I heard that there was no health hazard. In addition, copper is famous for Bordeaux mixture as a fungicide for viticulture, and since there is no health hazard due to these three elements, the upper limit is not set like cadmium.

Iron is a large amount of element as a constituent of soil, and since it dissolves easily, it was 10 to 60 mg/kg of brown rice. The amount of copper was 4 to 10 g/kg, which is about one tenth of that of iron. Manganese weighs 0.4 to 1.6 mg, which is one-tenth that of manganese, and is thought to be absorbed by paddy rice at a rate similar to that in soil.

3.5 Lead, Chromium and Arsenic Present in Japanese Soil

The quantitative value of lead shown in Fig. 6 lacks reliability as an absolute value due to the favorable sensitivity analysis, but it is a value of about a trace as an order. Generally, 100 mg or less is questionable as a quantitative value. In other words, it can be concluded that the trace level is contained in brown rice. Chromium shown in Fig. 7 is a metal often used in tableware such as chrome plating, and is also contained in stainless steel products. Although organic chromium and hexavalent chromium are harmful, it is considered that there is no risk of oral ingestion as such a chemical form under normal circumstances. Measurements also ranged from 50 to 150 mg/kg of brown rice. Chromium is a nutrient involved in glucose

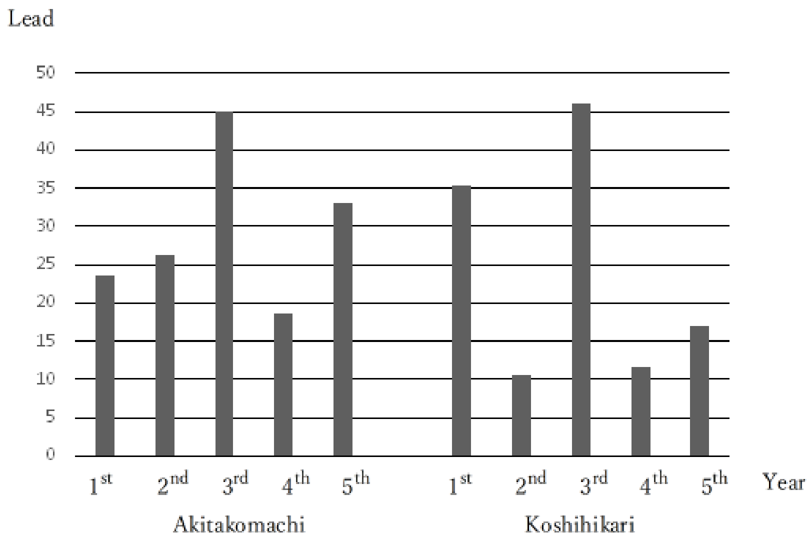

Fig. 6 Lead content in brown rice (μg/kg).

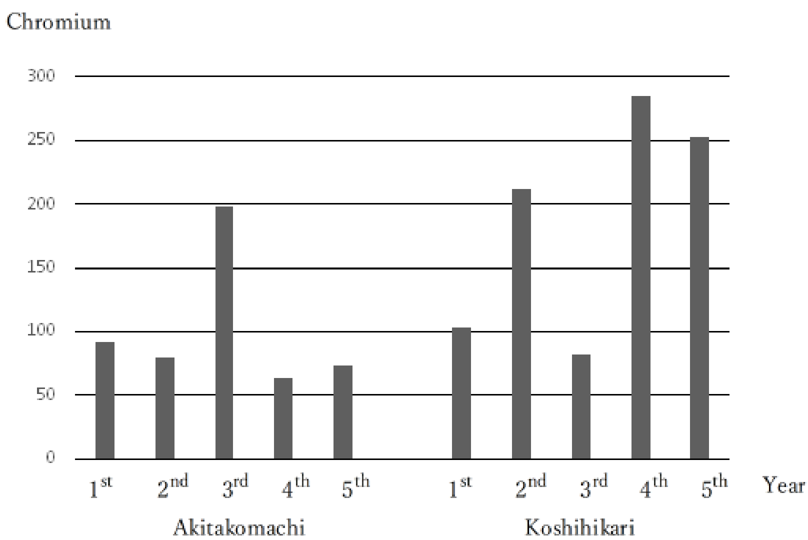

Fig. 7 Chromium content in brown rice (μg/kg).

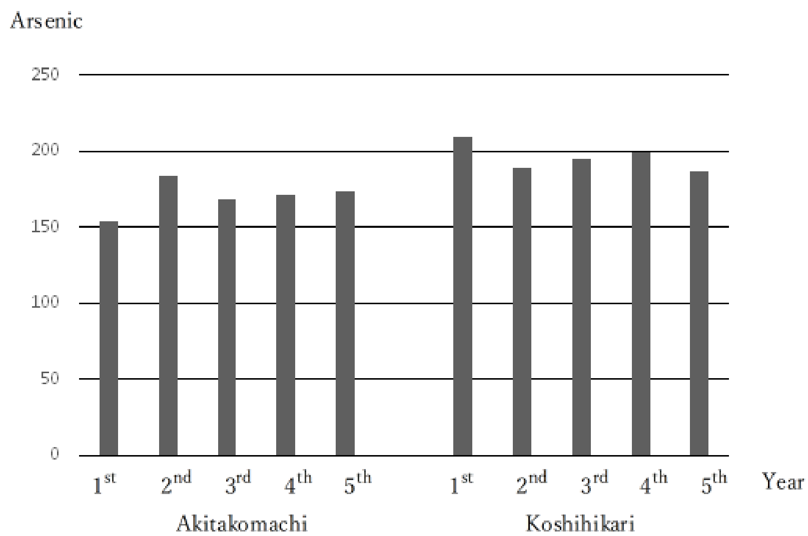

Fig. 8 Arsenic content in brown rice (μg/kg).

metabolism, cholesterol metabolism, connective tissue metabolism, and protein metabolism. The absorption rate of chromium varies depending on various factors, but the absorption rate is less than about 3%, which is a nutrient that is extremely difficult to absorb. The standard daily intake of chromium is 10 μg for both adult men and women, and considering 3% of the maximum 150 μg, assuming that 1,500 kcal is ingested only with sugar, from 150 g of brown rice Is calculated to be able to consume only 2 μg. Since we can conclude that this paddy rice is not enough, we need to consider taking it from other foods [14-20].

Fig. 8 shows the results of quantitative analysis of the amount of arsenic absorbed. Regarding the intake of inorganic arsenic, it is thought that the intake from "rice" accounts for about two-thirds, followed by "vegetables and seaweed". Regarding rice and hijiki, it has been confirmed that the ratio of inorganic arsenic to the contained arsenic is larger than that of other foods. In Japan, it is investigated that about 200 μg is ingested from rice and fish every day. This study showed that paddy rice cultivated using treated water from domestic wastewater weighs up to 150-200 μg per kg of brown rice. Assuming that all 1,500 kcal is taken from rice, 450 g of brown rice will give an inoculation dose of 67.5 to 90 μg, but it is clear that if such a diet is continued, another illness will occur. Half the amount of sugar, which is less than 750 kcal, is a normal diet, so it is halved there. Furthermore, since it is normal to polish rice and eat it in the state of white rice, it is reduced to about 10% of brown rice, so you will actually ingest about 3 to 5 μg. Some studies show that they consume 12.2 μg a day on average from rice. There is no health hazard due to arsenic in paddy rice cultivation using treated water from domestic wastewater. In addition, it can be concluded that rice was obtained at a level about one-third lower than the average amount of rice inoculated in Japan.

3.6 Effect of Removing Nitrogen and Phosphorus from Treated Water

The other aspect of the purpose of this study is to reduce the burden on the environment by removing nitrogen and phosphorus remaining in the treated water into paddy rice. As shown in the previous report [1], the apparent concentration of treated water is 3 mg or less of nitrogen and 1 mg or less of phosphorus per liter, but the total amount is enormous.

From Table 1, the total amount of water is 12,100 m^3 for Akitakomachi and 11,053 m^3 for Koshihikari. Nitrogen in the treated domestic wastewater operates close to the hobo discharge standard of 3 mg, and phosphorus of 1 mg or less is also very close to 1 mg.

Since running costs will increase if the cost is significantly lower than the discharge standard, it is a maintenance method to operate the vehicle as close to the discharge standard as possible and not to exceed the standard value. In other words, since the operating target with a margin for safety is 80% achieved, nitrogen should be operated so that the average value is about 2.4 mg ≒ 2.5 mg, and phosphorus is 0.8 to 0.9 mg in terms of performance. It is the limit.

Table 2 shows the nitrogen concentration at the end of the field, that is, in the effluent. It can be considered less than 0.2 mg/L. In other words, 2.3 mg, which is obtained by subtracting 0.2 mg from 2.5 mg/L, was removed by rice cultivation in paddy fields. As for phosphorus, it was below the measurement limit, so it is not shown in the table, but it can be said that 0.8 mg of phosphorus was removed per liter. Multiplying these numbers by the total quantity, Akitakomachi is converted to 12,100 m^3 × 2.3 mg × 1,000 m^3 for nitrogen, and to convert to g, divide by 1,000. Divide by 1,000 again to convert to kg. You can get a value of 27.83 kg. Calculate in the same way to get the total result for 5 years.

Akitakomachi: nitrogen 27.83 kg, phosphorus 9.68 kg

Koshihikari: nitrogen 25.42 kg, phosphorus 8.84 kg

Then, this is converted into fertilizer.

Considering a fertilizer bag containing 8% of standard potassium nitrogen phosphate, Akitakomachi (27.83 ÷ 8) × 100 ≒ 350 kg. The calculation for phosphorus is 121 kg. When treated water is used, phosphorus is about one-third, so it can be expected that phosphorus will be added or nitrogen will be denitrified on the surface of the field (= ANAMMOX).

As a result, no phosphorus was added and no nitrogen-induced legginess or lodging occurred. Nitrogen supplied mainly from nitrate nitrogen on the surface of the field is absorbed by algae in the process of reduction and may be converted to ammonia nitrogen when decomposed after death. In the rhizosphere of paddy fields, the various microorganisms that gain energy in the process of converting nitrates to nitrites and ammonia are anaerobic bacteria. It is speculated that nitric acid may have been reduced to ammonia due to the presence of both. Since rice can only absorb ammonia nitrogen, most of the nitrogen is converted to nitrogen gas together with organic matter on the surface of the paddy field and returned to the atmosphere, and some nitrogen is used as ammonia through a complex ecosystem.

The planned amount of water for this treatment plant is 1,200 people and 240 tons per day. Since there are four seasons in Japan and paddy fields cannot be used in winter, assuming that the paddy fields were used for 7 months from March to October, about 50,000 m^3 of treated water can be further purified by the paddy fields. In other words, it is 125 kg of nitrogen, which is 1,563 kg = about 1.5 tons when converted to 8% chemical fertilizer. The rural population of Japan is about 27 million. When converted to the entire rural area, it is 33,750 tons, and when converted to the entire country, it can be seen that it is a huge number. A huge amount of cost will be incurred for facilities and equipment for secondary to tertiary treatment. It was shown that the burden on the environment can be reduced by actively using treated domestic wastewater for agriculture in rural areas and rural areas.

4. Conclusions

Recycling of domestic wastewater in rural areas is as fearful and difficult to use as pollution in urban areas. Furthermore, in terms of color, coloring, and concentration of nitrogen and phosphorus, the use of undernutrition crops in paddy rice cultivation continued to fail due to the special nitrogen and phosphorus nutritional requirements of paddy rice. By installing a humus bioreactor, wastewater from the treatment facility by a biological treatment system with nitrogen 3 mg and phosphorus 1 mg/L or less, which is close to the performance of the 2.5th treatment, reduced the main fertilizer for paddy rice cultivation. Furthermore, a farming method was developed in which a few grains of fertilizer were applied to the plant roots at the time of planting with a rice transplanter, and paddy rice could be cultivated in combination with the one-shot fertilizer application method.

At first glance, the treated wastewater has already reduced nitrogen and phosphorus concentrations, so it is easy to think that rice cultivation using paddy fields and agricultural use will not have a significant effect. However, calculations show that the planned amount of water for this treatment plant is 1,200 people and 240 tons per day. Since there are four seasons in Japan and paddy fields cannot be used in winter, it is possible to purify approximately 50,000 m^3 of treated water with paddy fields, assuming that the paddy fields were used for seven months from March to October. In other words, it is 125 kg of nitrogen, which is a large figure of 1,563 kg = about 1.5 tons when converted to 8% chemical fertilizer. The rural population of Japan is about 27 million. When converted to the entire rural area, it is 33,750 tons. Equipment for tertiary treatment incurs a huge cost burden, but using wastewater from biological treatment systems for agriculture not only creates water resources, but also removes nitrogen and phosphorus emitted into the environment. It was shown to make a significant contribution.

Acknowledgment

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