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An Overview of the Studies on Biochar Fertilizer Carried Out at the Beginning of the Twentieth Century in Japan

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Additional information is available at the end of the chapter

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Abstract

Biochar is a recently coined term for charred organic matter used as a soil amendment. Although the term is relatively new, the substance has been used for a long time throughout the world, including Japan. After we read a Japanese book entitled *Nibai Shukaku Tenri Nouhou* (*How to Double Crop Yield by Almighty Farming System*) originally published in 1912, we found that there were conflicting opinions between the author (Mr. Katsugoro Oyaizu) and soil scientists of the time (Dr. Gintaro Daikuhara and others) on the benefits of the use of biochar fertilizer. Previous publications on this topic have been written in Japanese from a sociological viewpoint. By referring to the literature published at the beginning of the twentieth century in Japan, we attempt to shed light on the conflict between traditional knowledge of biochar fertilizer and new concepts of soil science imported from the Western countries. We also describe briefly the socioeconomic impacts on the use of biochar fertilizer in the later generations.

Keywords: agricultural chemistry, biochar fertilizer, Japan, Meiji and Taisho periods (1868–1926), modernization

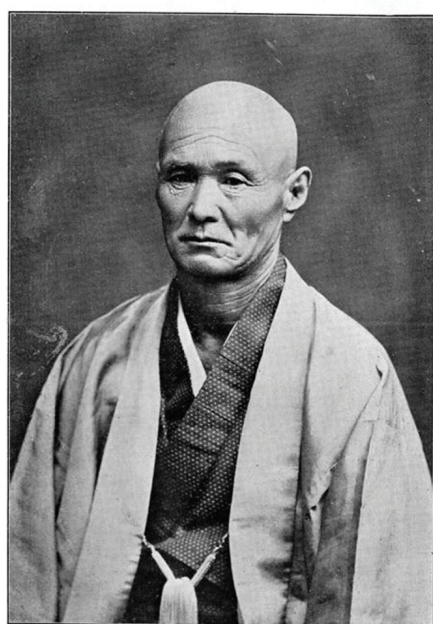
1. Introduction

“Biochar” is a recently coined term used to denote a carbon-rich product obtained when biomass, such as wood, manure or leaves, is heated with little or no available air. It is similar to the term “biosolid,” which is used to describe treated sewage sludge for agricultural use. The term biochar only applies to the material used as a soil amendment and is distinguished from charcoal used for fuel or as a reductant [1].

In Japan, material containing biochar has long been used as a fertilizer to improve soil quality and to increase crop production. For example, it is described as *yaki-goe* (burned fertilizer) in *Nogyo Zensho* (an encyclopedia of agriculture), which is one of the earliest agricultural textbooks called *nosho* and was written by Yasusada Miyazaki and published in 1697 during the Edo period (1603–1868). After reading the book *Nibai Shukaku Tenri Nouhou* (*How to Double Crop Yield by Almighty Farming System*) published in 1912 [2], we also found that there were conflicting opinions between the author and scientists who doubted the benefits of the use of biochar as a fertilizer.

Mr. Katsugoro Oyaizu, an agricultural extension worker, wrote the book and strongly advocated the use of *kuntan hiryo* (biochar fertilizer) for various crops [3]. Oyaizu was born in 1847 in Aichi Prefecture. In about 1880, he began to conduct agricultural experiments and promoted the use of heated soil as a fertilizer. From 1887 to 1888, he served as an agricultural extension worker in Aichi Prefecture. Based on his knowledge of heated soil fertilizer, he proposed a method to produce biochar fertilizer to the government in 1900 and summarized it in his book, which became a bestseller.

Dr. Gintaro Daikuhara was one of the scientists who disagreed with Oyaizu on the effects of biochar fertilizer. Daikuhara was born in 1868 in Nagano Prefecture, and thus was about 20 years younger than Oyaizu. A year after graduating from the College of Agriculture, Tokyo Imperial University (the predecessor of the University of Tokyo) in 1894, he joined the staff of



天理農法燻炭肥料發明者
小柳津勝五郎翁



Figure 1. Photographs of Katsugoro Oyaizu (left) and Gintaro Daikuhara (right). The photo of Oyaizu is reprinted from his book [2], and the photo of Daikuhara is reprinted from a collection of his papers [11]. The dates of photographs are not known. Reproduced from our study [12] with permission from the Japanese Society of Soil Science and Plant Nutrition.

the Imperial Agricultural Experiment Station where he served as an agricultural chemist for 27 years [4]. His publications on soil acidity [5] and a new method of its determination [6] attracted worldwide attention [7]. He also wrote textbooks on soil science in Japanese [8, 9], which contributed to establishing the basis of modern soil science in Japan [10].

Figure 1 shows the photographs of Oyaizu and Daikuhara. Both of them studied the effects of biochar fertilizer, but reached different conclusions. This episode has been written by several researchers, mainly by historical sociologists (for example, see [3, 12–14]). But these reports are available in Japanese only, and they are often written from a sociological viewpoint with limited insight to the experimental data.

In this chapter, we introduce these two agronomists and their thoughts on the use of biochar fertilizer with a parallel focus on the growth of modern soil science and fertilizer market in Japan. By referring to the publications of Oyaizu and Daikuhara et al, we attempt to unveil the conflict between traditional knowledge of biochar fertilizer and new concepts of soil science that had been imported from the Western countries in the early twentieth century. We also describe briefly the socioeconomic impacts on the use of biochar fertilizer in the later generations.

2. The fertilizer market in the beginning of the twentieth century in Japan

The Meiji period started in 1868 and ended in 1912. During this period, the Japanese people eagerly took in new ideas about culture and civilization from the Western countries. It was towards the end of the Meiji period when Oyaizu and Daikuhara crossed paths. At that time, new developments in agricultural technology and transportation had increased the demand for fertilizer. To meet the demand, new types of commercial fertilizers such as soybean meal, animal bone meal and chemical fertilizers were being imported into Japan [15].

In spring of 1896, Mr. Yasuie Suzuka, who was the president of fertilizer trading company, was taught by Dr. Jun Sawano, who was the first director of the Imperial Agricultural Experiment Station, that ammonium sulfate was a promising fertilizer and worth importing. Suzuka then imported 5 tonnes of ammonium sulfate for the first time from Australia [15]. In the beginning, however, it was difficult to sell the ammonium sulfate “medicine” to fertilizer dealers [16]. To ensure the quality of ammonium sulfate and enlarge its market, Suzuka relied on fertilizer testing services offered by the Imperial Agriculture Experiment Station [15].

Fertilizer testing services had been available since the founding of the station in 1893 [17]. The Fertilizer Regulation Act was put into operation in 1901, and the number of requests increased rapidly. The number of employees at the station increased, and a method for fertilizer analysis was established. The book *Standard methods in agricultural chemistry* [18] identified the following properties to be tested: moisture, ash, organic matter, nitrogen, phosphorus and potassium. The concentrations of nitrogen, phosphorus and potassium in a fertilizer were regarded as the most important properties.

From the 1900s to the 1930s, the ammonium sulfate market in Japan shifted from importation to domestic production. In 1902, sales of commercial fertilizers was largest for soybean meal (28% of the total amount), which was followed by fish meal of herring and sardine (27%), chemical fertilizers (14%) and rapeseed oil cake (13%) [19]. Chemical fertilizers included superphosphate, ammonium sulfate and sodium nitrate, but the percentage of their sales to the total amount was slightly more than 10%.

In the 1910s, the Haber-Bosch process of ammonia synthesis was invented in Germany. The rapid German commercialization of the Haber-Bosch process, however, was not followed by a similarly rapid conquest of the world fertilizer market [20]. In 1913, Chile, possessing huge deposits of sodium nitrate, was the largest producer of nitrogen in the world (56.5%) and Germany was the second (15.6%) [21]. At that time, Japan accounted for only 0.5% of world production. As shown in **Figure 2**, production increased rapidly thereafter. By 1934, Japan accounted for 10.5% of world production and had become the third largest producer in the world after Germany (23.5%) and the United States (13.0%).

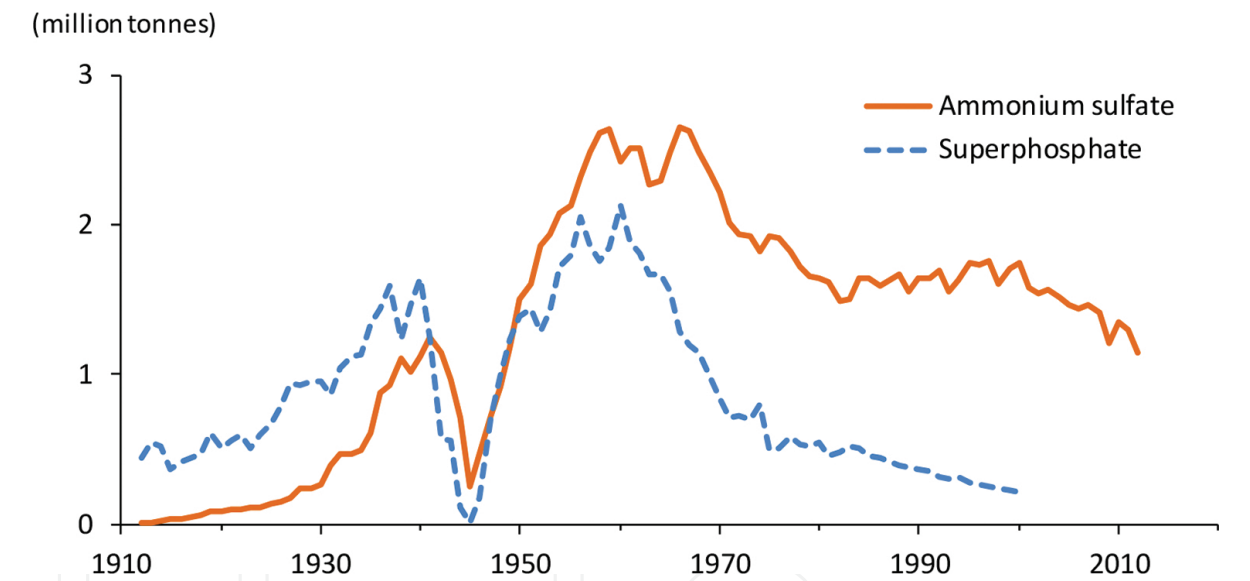


Figure 2. Annual production of ammonium sulfate and superphosphate in Japan during the Taisho (1912–1926), Showa (1926–1989) and Heisei (1989–present) periods. The values were derived from data in several fertilizer handbooks published by the Association of Agriculture and Forestry Statistics, Tokyo.

3. The conflict between Oyaizu and Daikuhara on biochar fertilizer: ca. 1890–1912

The conflict between Oyaizu and the scientists began in about 1890. A year after Oyaizu published a leaflet on methods to produce fertilizer by heating soil [22], Dr. Oskar Kellner, a German agricultural chemist who had been invited to teach agricultural chemistry at the Komaba School of Agriculture (the predecessor of Faculty of Agriculture at the University of Tokyo) reported that production of such fertilizer was worthless [23]. His comments were

based on an analysis by Dr. Max Fesca, a German agronomist who also taught agronomy at the Komaba School of Agriculture.

The article appeared in 1887 began by noting that heated soil fertilizer had already been reported as having a number of merits in *Nogyo Moukun* (agricultural textbook) published by Shosaku Itoh in 1840. Kellner said, "Someone appeared recently who engages in the production and extension of heated soil fertilizer, but the outcome is not always satisfactory". By "someone" Kellner clearly meant Oyaizu, although his name was not used. Kellner pointed out that, in order to evaluate the benefits of heated soil fertilizer, it is necessary to examine the effect of heating treatments on the content of fertilizer elements in the soil. Analytical results were provided by Fesca. A soil sample was treated with heat followed by addition of an ammonia solution. The soil samples (untreated soil, heated soil and heated soil treated with an ammonia solution) were subjected to extraction with about 10 mol L⁻¹ hydrochloric acid, and the concentration of fertilizer elements in the extracts was determined. The concentration of nitrogen in the heated soil was less than half of that in the original soil. Volatilization of ammonia during the heating and watering treatments was indicated. The concentrations of phosphorus and potassium were not different among the samples. It was concluded from these results that the use of heated soil fertilizer was neither effective nor economical.

Years later, Oyaizu recalled this event [2] and wrote, "Mr. Fesca, a German specialist employed by the Ministry of Agriculture and Commerce, reported that heated soil fertilizer is of no value. My business suffered a setback."

Some of the Japanese agronomists who were taught by Kellner and Fesca also criticized the leaflet written by Oyaizu [3]. It is likely that Daikuhara was also influenced by these German teachers. From 1897 to 1990, Daikuhara carried out an extensive survey on heated soil fertilizer at the Kinai Branch of the Imperial Agricultural Experiment Station in Osaka Prefecture [7].

In a report entitled "Studies on heated soil fertilizer" [24] and published in 1901, Daikuhara wrote, "The effects of heated soil fertilizer have been experienced by local farmers and recorded in old books." He reported that heated soil fertilizer was still being produced in 10 of Japan's 47 prefectures and that it was frequently used in Hyogo, Hiroshima, Oita and Tottori Prefectures. Unlike some of his colleagues, however, Daikuhara did not completely agree with the conclusions of Kellner and Fesca. He wrote, "Mr. Fesca used strong hydrochloric acid for extracting soil samples. This method is not suitable to evaluate the content of soil nutrients available to crops. I agree with his comment on the loss of nitrogen by volatilization. For the other elements, however, the content of plant-available fraction must have been influenced by the heating treatments. This could be revealed by extracting samples with dilute acid solutions instead of strong hydrochloric acid."

Daikuhara prepared heated soil samples by heating soil in a pan for 20 minutes. For the analyses, he used 1% solution of hydrochloric acid, oxalic acid and citric acid as well as strong hydrochloric acid solution. He also conducted plant growth experiments several times (**Figure 3**) and obtained new findings. Most importantly, he found that the contents of nitrogen, phosphorus and potassium extracted by dilute acid solutions were increased in the heated samples, whereas the whole contents of nitrogen and organic matter were decreased. In this

way, he determined the fraction of soil nutrients available to plants and succeeded in obtaining soil analytical results which agreed with crop growth better than before.

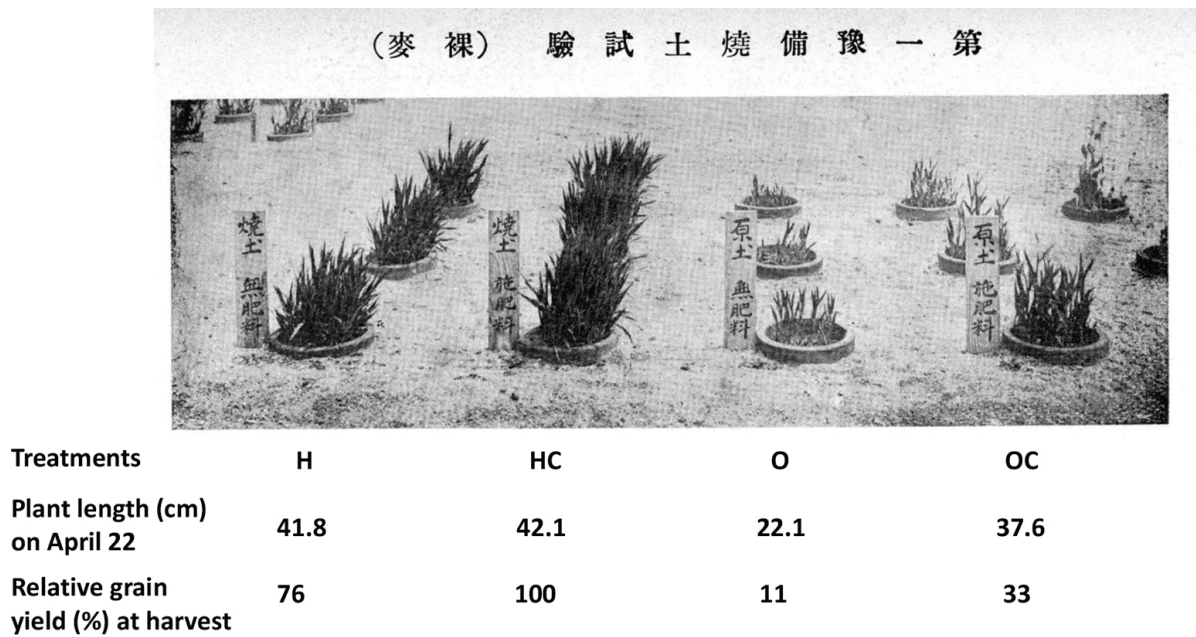


Figure 3. Barley grown with heated soil fertilizer and/or chemical fertilizer (N, P and K) in Daikuhara’s first preliminary experiment [24]. The photo and the data are cited from a collection of his papers [11]. The photo was taken in the middle of April 1898 at the Kinai Branch of the Imperial Agricultural Experiment Station, Osaka Prefecture. The four treatments in the picture are heated soil without chemical fertilizer (H), heated soil with chemical fertilizer (HC), original soil without chemical fertilizer (O) and original soil with chemical fertilizer (OC). This preliminary experiment was carried out in the open system using an earthen pipe as a pot and a sandy soil as a growth medium. The growth and yield of barley in the OC treatment were better than those of the O treatment, indicating that the growth was limited by fertilizer elements. Furthermore, the growth and yield in the H and HC treatments were better than those of the OC treatment. If we assume that the growth of barley was limited by nitrogen, then the inhibition of nitrification by soil heating (for example, see [25]) and the prevention of downward leaching of very mobile nitrate in a sandy soil may be responsible for the better growth in the H and HC treatments in addition to the enhanced mineralization of soil organic nitrogen by heating [26].

Daikuhara was the first Japanese scientist to use a dilute acid solution to extract nutrients from soil. According to his study [27], he had been impressed by pioneering work by Dr. Bernard S. Dyer published in 1894 [28]. Dyer was an agricultural chemist in the United Kingdom who proposed the use of a solution of 1% citric acid to determine whether a soil is in need of phosphate fertilizer. Dyer wrote in his paper, “It may be said to have been pretty widely recognized that some very much weaker solvent than strong mineral acid ought to be used in soil analyses, if these are to be of much use as indications of the proportion of available mineral plant food.”

Although the overall results indicated that heated soil fertilizer can be valuable, at the end of the report, Daikuhara added the following supplementary note: “The heated soil fertilizer analyzed in this report is different from the so-called new fertilizer composed of a mixture of charred straw and human waste. Currently, someone is encouraging the use of this fertilizer.

But its value is not worth describing at all.” Again, this “someone” was Oyaizu, and the “new fertilizer” referred to biochar fertilizer.

What was the difference between heated soil fertilizer and biochar fertilizer? Both fertilizers are prepared by smoldering organic matter. In the case of heated soil fertilizer prepared in the fields, plant residues such as tree branches, mulberry branches and rice husks are covered with soil, and a mound of soil is prepared. After setting fire to plant residues in the mound, the surrounding soil is treated with heat for several days (**Figure 4**). The product thus prepared is a mixture of heated soil, ash and charred materials. The heated soil fertilizer that Oyaizu recommended in the leaflet [22] was produced in a similar way but in a kiln. The main ingredient was rice stubble and soil together with rice straw as a fuel. After smoldering these materials, other ingredients (sulfur, human waste, salt and fish meal) were added to harmonize the composition of fertilizer.



Figure 4. A mound of soil smoldered for the production of heated soil fertilizer. The picture is reprinted from a leaflet of an Okuno-type apparatus to prepare heated soil, which was produced and sold by Marukome Shokai. The date of photograph is unknown, but it is probably from about 1935. Although buried and unseen in the picture, this apparatus made of iron was the most popular type before the Pacific War (1941–1945). The production of the apparatus was restricted severely by the shortage of iron during the war [29].

To prepare biochar fertilizer, Oyaizu recommended preparing a hole with a depth of about 1.4 m and a diameter of 1.8 m [2]. A bundle of rice straw is then set on fire and thrown into the bottom of the hole. Subsequently, additional plant residues of any kind are thrown into the

hole several times until white smoke emerges without a flame. After a few hours of smoldering, diluted human waste is poured onto the charred materials. The last step can be omitted when green grasses are used as an ingredient.

Because heated soil fertilizer contains heavy soil and biochar fertilizer does not, these materials are expected to be different in terms of the weight per unit volume. However, what Daikuhara wanted to say in the above note was not such a scientific matter but his opinion that biochar fertilizer cannot become as valuable as heated soil fertilizer.

Oyaizu was angry at the reaction by scientists, and wrote [2], “In 1900, I submitted the outcomes from experiments to the Ministry of Agriculture and Commerce, so that biochar fertilizer would be produced widely. As a result of the analysis by the authorities concerned, however, the biochar fertilizer was regarded as valueless in the same way as the heated soil fertilizer I proposed before. The authorities and scientists rejected all of my results. This event disappointed me very much.” The Imperial Agricultural Experiment Station was the “authorities concerned” to which Daikuhara belonged at that time.

In such circumstances, Oyaizu was supported by Mr. Masayoshi Inoue, a bachelor of agriculture who had made efforts to support the use of biochar fertilizer. Inoue wrote [30], “So-called agronomists did not pay any attention to biochar fertilizer on the grounds that it contained little nitrogen, phosphorus and potassium.” Inoue also referred to Daikuhara’s report on heated soil fertilizer and complained, “On heated soil fertilizer, a certain doctor at the Imperial Agricultural Experiment Station in Tokyo published a report. But he focused on the effect of soil heating only. Charred materials present in the heated soil fertilizer were not described at all.” The “certain doctor” is Daikuhara. He had moved from Osaka to Tokyo in 1903 [7]. As noted above, he prepared a heated soil sample in a manner different from local farmers, and there was no biochar in his samples.

Why did Oyaizu believe in biochar fertilizer, despite the criticism from the agronomists? This is probably because he had conducted field trials by himself and with many farmers and found empirically that the application of biochar fertilizer improved crop productivity (**Figure 5**). In his book [2], he wrote, “In order to support the growth of living crops, it is necessary to apply a living body to them.” and “Biochar fertilizer is a living body which provides the following functions; 1) absorption and preservation of heat, 2) absorption of moisture, 3) absorption of nitrogen, 4) effects on sterilization, and 5) effects on soil quality.” According to the traditional classification of fertilizers by Nobuhiro Sato in the Edo period, “a living body” is a type of fertilizers originating from living creatures (mainly animals) such as human waste, horse dung and fish meal. Although Oyaizu had written that he was impressed by the thoughts of Sato and the biochar fertilizer he proposed did contain human waste, it is not clear whether Oyaizu followed the traditional definition precisely. The term “a living body” was omitted by his son, when the book was revised and enlarged in 1915 [31]. We can at least safely say that Oyaizu considered that the effect of biochar fertilizer was not limited to the contents of fertilizer elements, but it extended to its capacity to absorb heat, water and nitrogen.

(二十) 西ヶ原農事試験場にて炭燻る麦の栽培

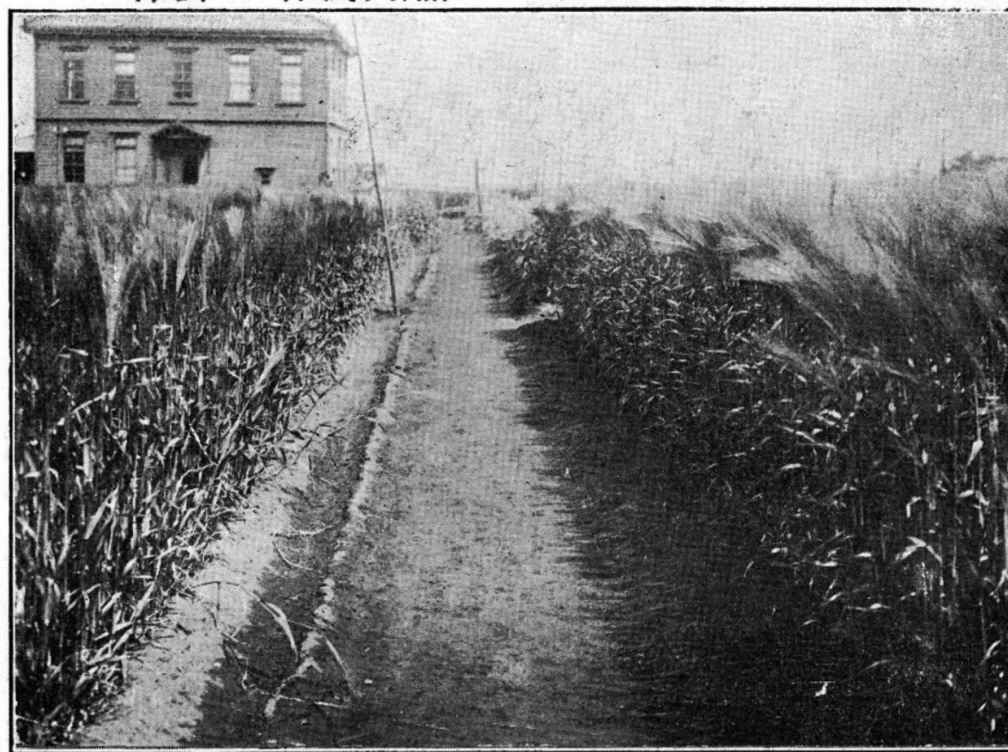


Figure 5. *Mugi* (probably barley) grown at the Imperial Agricultural Experiment Station (Nishigahara, Tokyo) in 1912, with an aid of a political party “*Dai-Nippon Koudou Kai*” to Oyaizu. *Mugi* is a general Japanese term including wheat and barley. The picture is reprinted from the book revised by Oyaizu’s son [31]. Plants on the right were grown with the application of biochar fertilizer, whereas plants on the left were grown by the conventional method. The Oyaizu group and the Experiment Station began collaborating on the cultivation of *mugi* with biochar fertilizer in 1910, but few quantitative results were reported by the station [2].

In the first chapter of his book [2], Oyaizu expressed his viewpoint as follows, “It is evident that Western science, however progressive it is, is not a universal truth. I cannot understand why so-called scientists in our country are eager to copy it. Originality is most important, because we, Japanese, have traditional knowledge of agriculture.” A year after the book was published, Oyaizu passed away. Following the wishes he expressed, the coffin was filled with biochar fertilizer [3].

It should be noted that we have interpreted Oyaizu’s words as we understand them. His intended meaning might have been different from our interpretation. Although we had trouble in understanding parts of it, his book starts with the theory of Yin and Yang, the Chinese philosophy that has influenced the development of science in Asia, including Japan (the so-called Eastern science) (**Figure 6**). Harmonization of fertilizer according to the Yin and Yang theory was regarded as critically important in *Nogyo Zensho* by Miyazaki; for example, *yaki-goe* (burned fertilizer) should be used in combination with *mizu-goe* (liquid fertilizer containing human waste) for the harmonization of Yin and Yang in order to support the growth and ripening of crops by the power of Yin and Yang, respectively [32]. Therefore, it is not an exaggeration to say that the conflict between Oyaizu and Daikuhara was representative of the

larger struggle between the two established philosophies, one from the East and the other from the West.

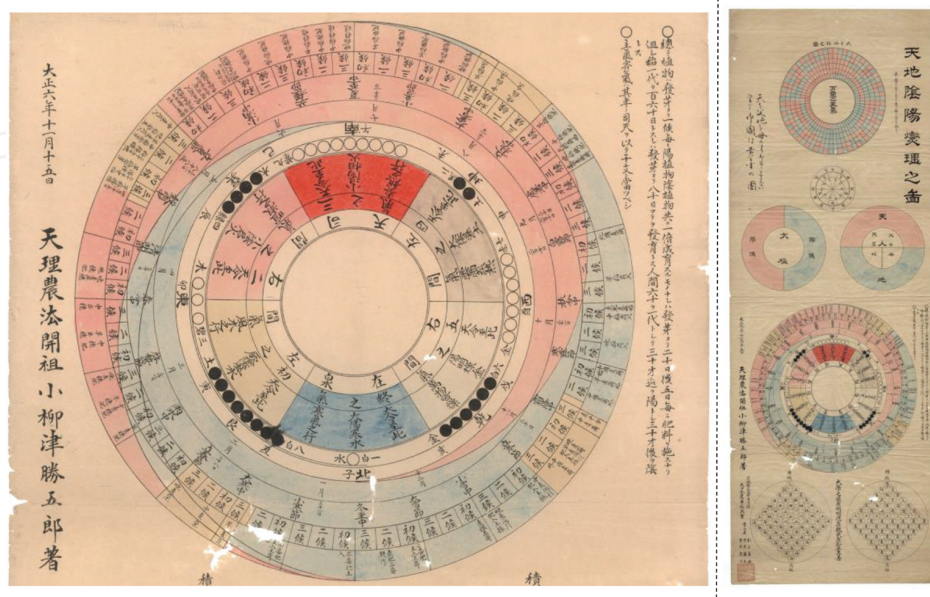


Figure 6. A circular crop calendar proposed by Oyaizu and printed in 1917 after his death (left). In the circle, summer and winter are depicted in red and blue colors, respectively, and the seasons rotate clockwise. Field management is described in the inner peripheral part. This calendar is designed to inform farmers on the suitable seasons for each field management practice in the double cropping of rice and *mugi*. It is a part of the schematic diagram called “Harmonization of Yin and Yang” with the length and width of 105 cm and 39 cm, respectively (right). The contents of the calendar are also explained in Oyaizu [31].

4. Additional descriptions of biochar fertilizer by Daikuhara: ca. 1912–1920

As noted above, Oyaizu proposed a method to produce biochar fertilizer to the government in 1900. The Imperial Agricultural Experiment Station began experiments on biochar fertilizer in 1908. As a response to Oyaizu’s popular book, a comment of the station’s director (Dr. Yoshinao Kozai) appeared in a newspaper *Jiji Shinpou* on July 25, 1912. In the article, Kozai expressed his personal opinion. He said, “It is great if the proposed biochar fertilizer can increase the crop yield by 20–30%,” but also added, “It is premature to make a judgement, because the results from our station are not yet satisfactory and the research is still ongoing.”

A year later, a comment of the chief of agriculture department in the Ministry of Agriculture and Commerce (Mr. Hitoshi Douke) also appeared in a newspaper *Tokyo Asahi Shinbun* on November 27, 1913. In the article, Douke said, “We have compared biochar fertilizer with conventional fertilizer for 4 years at several stations, including Nishigahara (Figure 5). But we could not find such a big effect as has been reported by some advocates.” He continued, “Growing crops with biochar fertilizer requires labor several times more than that with

conventional fertilizer. It is premature to say that biochar fertilizer is excellent only from the data of the crop yield.”

In April 1915, two years after the death of Oyaizu, Daikuhara gave a lecture on soil and fertilizer at Kanagawa Agricultural Experiment Station [33]. In reference to biochar fertilizer, he said, “Biochar fertilizer has been promoted in the past few years. But it should be kept in mind that similar fertilizer had been produced for a long time before it attracted public attention.” He introduced several examples of traditional biochar fertilizers in Japan and continued, “Biochar fertilizer is only charred organic matter. It does not have any special function. If I need to say more, biochar fertilizer will improve soil physical properties to some extent. Potassium and phosphorus in the ingredients will be solubilized during the process of production. Some of the nitrogen in biochar fertilizer will be available to crops, but the nitrogen supplied from biochar fertilizer should be ascribed to human waste added to the charred materials.”

In the lecture, he noted that the contents of nitrogen, phosphate and potassium in biochar fertilizer were 0.6–0.7%, 0.3% and 0.6%, respectively. He also presented results from a pot experiment in which barley was grown as a test plant. He suggested that decomposable organic matter such as rice straw should be used for the production of compost, whereas slowly decomposable organic matter such as fallen leaves might be more suitable in production of biochar fertilizer. The lecture ended with the following statement, “Furthermore, if we continue to apply a fertilizer with low organic matter content, it is apparent that soil organic matter will decrease gradually and soil fertility will be depleted.” He emphasized that about half of the organic matter was lost during the production of biochar fertilizer.

Daikuhara’s view of biochar fertilizer had become slightly more positive over time. Inoue stated [30], “In past years, a certain doctor visited Chiba Prefecture. He was surprised very much to see the vigorous growth of crops to which biochar fertilizer had been applied.” Again, “a certain doctor” referred to Daikuhara. In February 20, 1908, Daikuhara visited Mr. Yajima Chiba together with Mr. Tadaharu Kato, who was a principal of Mobara Agricultural School. Chiba explained how to grow *mugi* (a general Japanese term including wheat and barley) with biochar fertilizer [34].

Did Daikuhara pay attention to the rate of decomposition of biochar or compost after their application to soil? Now it is well known that biochar is stable in the environment and decomposes very slowly in soil. In the first volume of his textbook entitled, *Dojyogaku Kougi* (*Lectures on the Science of Soils*) [8], he cited his own results [24]. He wrote, “There is no doubt that the heating treatment not only affects soil microbes but also accelerates the breakdown of soil components”. To support this, he referred to partial sterilization, a phenomenon discovered around 1900. Daikuhara paid attention to works by Sir Edward John Russell and his colleagues in the United Kingdom. Darbishire and Russell [35] demonstrated that partial sterilization of soil by heating to 100°C leads to a marked increase in the amount of oxygen absorbed by microorganisms of the soil. Absorption of oxygen by microbes and the release of carbon dioxide from soil are essentially two sides of the same coin. It follows that Daikuhara knew about the microbial decomposition of organic matter when he made his lecture on biochar fertilizer in 1915. But it is unlikely that he was aware of the very slow decomposition of biochar in soil.

In the second volume of his textbook [9], Daikuhara stressed the importance of the maintenance and improvement of soil fertility. At that time, the three fertilizer elements (nitrogen, phosphorus and potassium) were known to the public, and the effects of chemical fertilizer were exaggerated. Daikuhara criticized the crowd of “three-element admirers,” possibly in a similar frame of mind that Oyaizu had toward Daikuhara. He wrote that soil fertility is controlled by various factors, including chemical factors such as the contents of nutrients and organic matter, and also physical factors such as aggregate structure, soil depth and moisture content. He emphasized that application of three elements in the form of chemical fertilizer was not the only solution and that application of organic matter and lime to soil is indispensable, considering the climate, soil type and farm management in Japan. His thoughts had become more holistic. This may have been related to his extensive research activities, especially on the denitrification after application of sodium nitrate to paddy soil [36] and on the acidification of soil after application of potassium salt [5].

Part of his wishes was realized by younger soil scientists, including Dr. Matsusaburo Shioiri. In Konosu experimental field of the Imperial Agricultural Experiment Station, the longest field experiment in Japan was started from 1925 with the aim to evaluate the effect of application of organic and chemical fertilizers on the yield of rice and wheat and the fertility of soil [17]. It was about 80 years after the world’s longest field experiment had been launched by the Rothamsted Experimental Station in the United Kingdom [20].

In 1921, Daikuhara was appointed as a professor at Kyushu Imperial University. Two years later, he was appointed as the Director of the Agricultural Experiment Station in the Province of Korea. After this, he became the President of Kyushu Imperial University and Doshisha University. While working actively as the President of Doshisha University, he passed away in 1934 [4]. His series of textbooks on soil science was to be composed of three volumes, but the final volume remained unpublished [10].

5. The use of biochar fertilizer during and after the Pacific War in Japan: ca. 1940–present

From the present perspective, we feel that both Oyaizu and Daikuhara devoted themselves to improving Japanese agriculture from a holistic viewpoint. In the last section, we briefly examine the influence of their achievements on later generations.

In December 1941, Japan triggered the Pacific War. During the war, the production of ammonium sulfate decreased sharply from 1.24 to 0.24 million tonnes per year (**Figure 2**). The production of superphosphate also decreased to as little as 0.01 million tonnes per year. These sharp decreases were because imports of the key ingredients were stopped by the war and also because the ammonia produced by the fertilizer industry was converted to nitric acid due to the critical demand for the production of explosives [21]. In addition, the production of commercial organic fertilizers such as rapeseed oil cake and fish meal also decreased during the war.

Because of the shortage of all commercial fertilizers, the government encouraged farmers to produce traditional homemade fertilizers, including heated soil fertilizer [37] and biochar fertilizer. Dr. Shingo Mitsui, an outstanding soil scientist, began to reevaluate and extend the findings of Daikuhara [38]. When he began these experiments in 1939, the use of heated soil fertilizer was almost extinct in Japan [26].

In a textbook of fertilizers published in 1942 by Dr. Hideo Misu [39], the biochar fertilizer proposed by Oyaizu was described as one of 178 types of fertilizer. The composition of the product (38–51% moisture, 0.74–1.06% nitrogen, 0.28–0.70% phosphate and 0.63–0.85% potassium) was reported to vary depending on the type of ingredients used for smoldering and the amount of human waste mixed in. This fertilizer was thought to have small direct effects from the fertilizer elements and some indirect effects from the charred carbon. In contrast to the previous negative descriptions of biochar fertilizer by scientists, a short biography of Oyaizu was published as an independent book chapter (at least twice in 1938 by Sakurai and 1941 by Iyoda), in which he was described as one of the great agricultural experts.

In August 1945, the war came to an end. A year after, Oyaizu's book [2] was republished again with some revisions [40]. It was more than a generation after the original was published. The title of the book was shortened by removing the word *Tenri* (almighty), and the first chapter was simplified by omitting the theory of Yin and Yang. These revisions suggest strongly that the Japanese people at that time accepted Western knowledge and that the theory of Yin and Yang proposed in the original was regarded as out of place or out of date.

In 1945, the capacity of factories in Japan to produce ammonium sulfate was only about 10% of the capacity in 1941 because of the insufficient maintenance of the equipment and also because of the air raids during the war [41]. After the war, the government put an emphasis on the production of ammonium sulfate [41]. Its production level had recovered by 1949 and peaked in 1959 and 1966 (**Figure 2**). During the period of rapid industrial growth, Japan's farming systems were modernized with the use of agricultural machines, pesticides and fertilizers. Traditional fertilizers, which required time and labor to produce, became to be regarded as old-fashioned. The textbook written by Misu was revised and republished in 1949 [42]. In the revised book, biochar was described more specifically as *mokutan matsu* (wood charcoal powder) having several indirect effects on crop growth. At the same time, the term *kuntan* (biochar) disappeared together with Oyaizu's name.

In the 1970s, the domestic production of rice became sufficient to meet demand. The government started to pay farmers to reduce rice production by introducing the *gentan* policy in 1970. Things began to change. The public attention to food shifted from the quantity to the quality. The environmental pollution caused by industrial activities had come to be widely recognized. By that time, Itai-Itai disease and two outbreaks of Minamata disease had been identified and were known to be caused by the improper management of wastes containing toxic metals by large incorporations in Japan.

Silent Spring, written by Ms. Rachel Carson in the United States, focused on the detrimental effects of pesticides on the environment and became popular around the world after its publication in 1962. In Japan as well, the newspaper *Asahi Shinbun* published the serialized

nonfiction novel, *Fukugou Osen* (*The complex contamination*) by Ms. Sawako Ariyoshi, in 1974. Her book [43] became a bestseller. In the book, Ariyoshi wrote that multiple contaminants at even trace levels may have cumulative or even synergetic effects on the environment and human health. She discussed several topics to make her readers aware that environmental pollution can be caused and suffered by everyone. One of the topics she described was the dark side of chemical fertilizer. Local farmers she interviewed said frequently that the “soil is dead,” probably due to the application of chemical fertilizer in excess for a long period.

From the late 1970s to the early 1980s, several scientists, especially Drs. Sugiura, Kishimoto and Ogawa, intensively examined the function of biochar as a soil conditioner for afforestation (for example, see [44]). On November 26, 1986, the government designated biochar powder (precisely, wood charcoal powder) and vermiculite as soil amendments, which are effective to improve soil quality, especially water permeability. Nowadays, charred rice husk as a soil amendment mainly for potted flowers and kitchen garden is usually sold at commodity household stores, and it is occasionally produced by rice-growing farmers (**Figure 7**). In addition to this, growing concerns on global warming highlighted the very slow decomposition of carbon in biochar, thereby returning carbon from the air to belowground through the application of biochar to soil, i.e., biochar carbon sequestration [1].



Figure 7. Mounds of rice husk being smoldered in a rice field to produce biochar. A dark-colored soil beneath the mounds is a volcanic ash soil distributed widely in Japan. The photo was taken by the authors in Ibaraki Prefecture on August 30, 2014 soon after the harvest of rice. The Waste Management and Public Cleansing Law (revised) was put into operation on April 1, 2001. The revised law prohibited the open burning of wastes except for several cases including the burning or smoldering of agricultural wastes by farmers in a field of their own.

Various possible applications of biochar in relation to agroecosystem management have been evaluated by many scientists worldwide. For example, Fischer and Glaser [45] proposed co-composting of fresh organic matter and biochar during the composting process. Their idea is

similar to Oyaizu's idea to harmonize the composition of biochar fertilizer by addition of human waste. Although we cannot go into detail here, we have also examined the effect of heating of sewage sludge on the mineralization of nitrogen [46] and the uptake of nutrients by a leafy vegetable [47]. These experiences led us to focus on the earlier works by Oyaizu, Daikuhara and Mitsui.

In addition to the agricultural studies, research has been carried out from the viewpoint of soil formation over the centuries. For example, *Terra Preta de Indio*, which is widespread in the Amazon basin, is a well-known anthropogenic soil whose high organic matter content is probably the result of the long-term input of biochar produced by pre-Columbian Indians [48] in combination with the stabilization of humic substances by aluminum and iron in the strongly weathered soils [49]. Likewise, the input of charred grassland plants that are highly stable in soil is hypothesized to be responsible for the formation of black, humus-rich volcanic ash soils distributed widely in Japan [50] (**Figure 7**).

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