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The Chemistry of Paddy Soils in Japan

(A Preliminary Report)

By

M. Shioiri
Professor, Tokyo Univ.

And

T. Tanada

Scientific Consultant, Hawaii Agr. Exp. Sta.

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Summary

1. During most of the rice season, paddy fields usually are flooded with irrigation water. This flooding and the high temperatures of the summer season result in marked chemical changes in the soil constituents. Therefore, to understand the chemical changes occurring in paddy soils during the rice season, the effects of flooding paddy soils with irrigation water should not be neglected.

2. In order to give a general picture of the investigations conducted on the chemistry of paddy soils in Japan during the last ten years, suitable reports published in Japanese have been selected and discussed briefly. Most of the investigations presented in this report were conducted at the Central Agricultural Experiment Station, Nishigahara, Tokyo, and at Tokyo University, Tokyo, by the author and his associates.

3. Because of its relatively easy adaptability to study and because of its importance in rice production, the transformation of soil nitrogen in the flooded paddy soil had been selected as the basis of most of the investigations conducted by the author on the chemistry of paddy soils.

The investigations first were conducted in the laboratory and, where possible, results were substantiated subsequently by field experiments.

4. The chemistry of degraded paddy soils is discussed in this report primarily from the viewpoint of productivity and methods for reclamation. The problem of degraded paddy soils is discussed primarily from the results of studies on the deficiency of free iron oxides which affect the roots of rice plants.

5. For a comprehensive understanding of the chemistry of both normal and degraded paddy soils, in addition to nitrogen and iron transformation, other important aspects of paddy soils such as the nature and role of active manganese, humus compounds, and the clay complex must be studied. Only a partial attempt has been made in this report to discuss these important factors.

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Introduction

1. The yield of rice is highly dependent upon soil fertility. This is evident in Table 1 and 2, which show the influence of nitrogen, phosphoric acid, and potash on the yields of small grain crops. The data were compiled from the results obtained during the first three years of long term continuous field experiments conducted at several prefectural agricultural experiment stations in Japan.

2. It is apparent from Table 1 and 2 that the influence of soil fertility is far greater on the yields of lowland rice than on the yields of other small grain crops. This fact is in agreement with the practices followed by Japanese farmers in treating soil for rice production. The farmers are familiar with methods to increase the availability of plant nutrients, especially soil nitrogen, contained in paddy soils. By a scientific analysis of such practices and various other information, it is possible to formulate some general principles of soil management for rice production which will contribute to the improvement of practical rice culture.

3. In this report the main emphasis is given to nitrogen transformation in flooded paddy soils which are relatively easy to study and are of primary importance in rice production.

4. The information for this report was prepared by Dr. Matsusaburo Shioiri, Professor of Soils, Tokyo University, Tokyo, Japan. His original manuscript was rewritten and organized by Mr. Takuma Tanada, Scientific Consultant, on leave from the Hawaii Agricultural Experiment Station, University of Hawaii, T.H., and Mr. F.M. Jornlin, Scientific Consultant, on leave from E.I. du Pont de Namours and Company, Wilmington, Delavare.

A. Profile Development of Paddy Rice Soils under Flooded Conditions.

1. Rice fields of Japan.

a. Rice is the main crop grown in Japan. Approximately three million hectares or half of the total arable land is planted to rice.

Rice fields are generally located on alluvial soils of recent origin found along valley bottoms, rivers, lakes, and seashores. Limited areas of rice fields also are found on soils of pleistocene plains and hillsides.

b. Rice fields may be broadly divided into two classes according to drainage. "Dry rice fields" are paddy fields which are well-drained and have well established irrigation and drainage systems. "Wet rice fields" are wet throughout the year because of a high water table. These classes are related to each other by intermediate or transitional forms. Formerly, large areas of low-lying rice fields belonged to the wet type, but, with the realization of higher productivity and profits from well-drained fields, many areas of wet rice fields have been drained successfully. Today most of the area of rice fields in Japan is of the well-drained type.

2. Cultivation Practices in Japan.

a. When a paddy field is flooded with irrigation water, the microbiological activities in the soil are promptly and considerably changed. Hence, to understand the chemical changes occurring in paddy soils during the growing season, it is necessary to know the cultivation method used for rice production in Japan.

b. The dry field is plowed to a depth of 10 to 15 centimeters in late autumn or spring. In spring the field is flooded with irrigation water and then is harrowed to puddle the soil in the furrow-slice. Sometimes the field also is harrowed before irrigation. After the field has been prepared in such a manner, rice seedlings are transplanted to it. When the young rice crop is growing, the field is flooded with water to a depth of a few centimeters. At the heading stage or two weeks after heading, the field is drained if practical to do so. After transplanting, weeds are removed four or five times every seven to ten days until the rice plants are tall enough to shade the field and prevent further growth of weeds. The initial application of fertilizer is applied before or after flooding. Top dressing with fertilizers, especially nitrogenous fertilizers, ordinarily is recommended at certain periods. The crop is harvested during September, in northern Japan to November, in southern Japan.

3. Chemical changes occurring in flooded paddy soils 14/ 26/

a. The plant association in the water covering the surface of the rice fields during the irrigation season is more like the plant association in the water of ponds and small lakes than that in the water of swamps. The characteristic plants in surface water of paddy fields are of the hydrophytic type comprised mainly of many kinds of algae and duckweeds. The growth of these hydrophytes usually is remarkable, especially during the early stages of the rice growing season. This is due to the application of fertilizers and abundant sunshine. 28/ The surface water of a flooded paddy field receives an ample supply of oxygen gas from the hydrophytes and from the atmospheres. In spite of the abundant sources of oxygen gas for the surface water, the influence of the oxygen in this water is confined only to the uppermost layer of the paddy soil, generally to a depth of few millimeters to one centimeter. This layer corresponds to an "oxidized layer" where microorganisms live aerobically. Below this zone is the "reduce layer" where microorganisms live anaerobically. The reduced layer constitutes the main part of the furrow slice. In contrast to the brown color of the oxidized layer, the reduced layer is bluish-gray in color due to the presence of certain ferrous compounds. In the rhizosphere of the rice crop, however, conditions are altered greatly. The soil particles attached to the roots of the rice plant are distinctly oxidized. This oxidizing power of roots is characteristic of marsh plants such as rice. 34/

b. The profile of a flooded paddy soil during the summer season, as described in the preceding paragraph, possibly may be compared with that of a swampy soil except for certain important differences. The dry rice fields are well-drained after the rice growing season. The result is that the whole furrow slice is under an oxidized condition during the drained period. Consequently, the microbial equilibrium which would have been established with the soil permanently flooded is disturbed for a while after drying and after irrigation. For a time after irrigation the activated heterotrophic organisms actively decompose certain soil organic matter, producing ammonium-nitrogen on one hand and consuming oxygen on the other hand. This gives rise to a reduced condition and the "reduced layer" described in the preceding paragraph is produced.

c. A summarized discussion of the transformation of nitrate-nitrogen in soils under water-logged conditions was given by De and Sarkar in 1936. 8/ Recently in Japan Aoki worked on this problem at Kyoto University giving special attention to the influence of soil treatments on nitrate reduction of added nitrate nitrogen under water-logged conditions. 1/

This paper places special emphasis on the differentiation of the oxidized layer and reduced layer in water-logged paddy soils. Autotrophic organisms are active in the oxidized layer. Nitrification by nitrifying organisms is characteristic of this thin layer. However, under the water-logged condition of a flooded paddy field, the nitrite-nitrogen or nitrate-nitrogen produced in oxidized layer soon is denitrified, probably at the boundary of the two layers, the oxidized layer and the reduced layer or in local reduced spots in the oxidized layer, by microbial processes and also by chemical processes. In paddy fields where concentrated nitrogenous fertilizers have not been applied, denitrification based on such a mechanism is not significant. However, if concentrated nitrogenous fertilizers, such as ammonium sulfate, fish meal, and soybean meal, are added to the upper layer of the paddy soil, which later may develop into the oxidized layer, the loss of nitrogen from these fertilizers may become very serious.

d. In the experiments cited in this report, soil samples which were incubated or analysed chemically were shifted through a 0.5 mm or 1 mm sieve to remove the roots and to secure better mixing. Samples received in the laboratory from the field were kept in a low temperature room at approximately 0° C if the experiments required prevention of undesirable chemical changes as a result of microbiological activities.

e. These methods of analysis also were used in other experiments described in this report.

4. Differentiation of the profile in flooded paddy soil.

a. An observation of the furrow slice of flooded paddy soil during the summer will often, but not in every case, reveal a thin layer of about 0.5 mm in thickness at the boundary between the narrow oxidized layer and the inner reduced layer, or actually, at the bottom of the oxidized layer. This thin interzonal layer is colored reddish brown by the deposition of much hydrated ferric hydroxide.

b. The subsoil of a well-drained paddy field usually remains in an oxidized condition even during the summer irrigation season. This is in sharp contrast to the overlying furrow-slice soil which is under reduced condition when flooded.

c. The manner of the peculiar profile development in the flooded furrow slice of paddy soils can also be observed under laboratory conditions. When a sample of the furrow slice of a rice field is left under water in a glass cylinder with summer temperatures being maintained, a profile is formed after several weeks similar to that produced in a flooded rice field under actual field conditions. By this time several deposited layers of hydrated ferric hydroxide are developed repeatedly and are separated by bleached layers of one to two millimeters in the lower portion of the oxidized layer.