Recent Factors Limiting Soil Fertility in Japan

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ABSTRACT

Recent problems of Japanese agriculture relating to soil fertility can be ascribed to two main factors: the diversification of the food habits of the Japanese people and the decrease in the numbers of farmers.

The former factor has resulted in the increase of production of various crops to reduce the accumulation of rice associated with the decrease in consumption. National plan for the utilization in 1990 of 0.83 million hectares (corresponding to 30% of the total rice field area, approximately) for the implementation of rotation between rice fields and upland fields has promoted research on water management and plowsole management. The diversification of the food habits, also, has stimulated the greenhouse cultivation of vegetables, fruits, etc. and the utilization of marginal land for the cultivation of special crops, in particular, slope areas, which have brought about salt accumulation and soil erosion, respectively. Moreover, the consumers' demand for domestic agricultural products of high quality has compelled the soil scientists to develop new and suitable methods of soil management, fertilizer application, etc.

The latter factor, namely the shortage of agricultural labour, has led to poor management of soil, including the application of an excessive amount of fertilizers, insufficient application of organic matter and to soil compactness caused by the intensive utilization of agricultural machinery. More appropriate methods of fertilizer application are currently being recommended in order to minimize the adverse impact on the environment. The monitoring of the changes in soil fertility is encouraged by national laws and government programs.

Introduction

Up to around 1960 after World War II, we could not grow our own food, and there was a food shortage. Therefore, the program for increasing the yield of crops, especially rice, was one of the major policies of the Japanese government. Improvement of degraded or poorly drained paddy soils, reclamation of paddy soils (Maeda, 1984), soil surveys for agricultural lands (Abe, 1982), etc. were carried out in order to increase the yield of crops.

Around 1960 the consumption of rice of the Japanese people began to decrease (Fig. 1) due to the changes in the food habits along with the development of the economy. In the first half of 1970, for the first time in our history we recorded an overproduction of rice, and the government began to control rice cultivation, in implementing measures for utilization of paddy fields for the cultivation of upland crops or rotation between paddy fields and upland fields.

The expansion of the industrial activity resulted in a migration of the labour force into the cities, and mechanization of agriculture was promoted to reduce the labour and support the industrial effort.

On the other hand, the food habits of the Japanese consumers became more diversified along with the improvement of the living conditions, which affected the agricultural policy as

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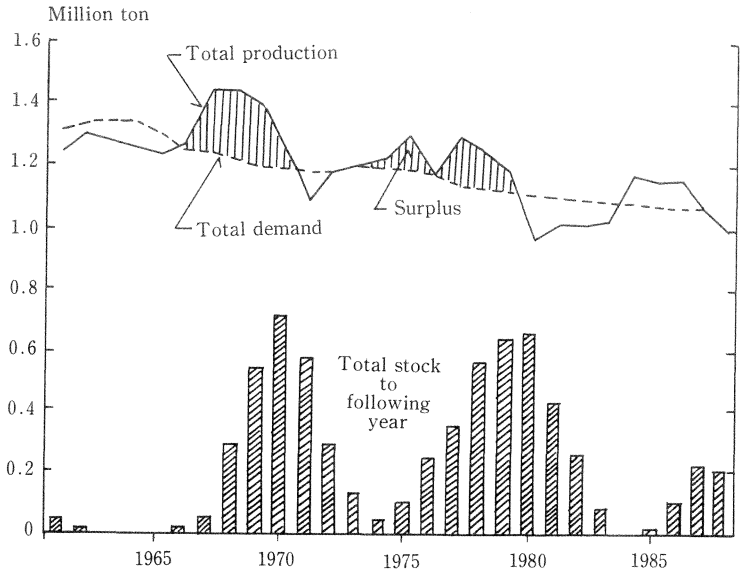

Fig. 1 Change of supply and demand of rice in Japan. Cited from Fertilizer Yearbook 1990.

well as the activities of the Agricultural Experiment and Research Institutions (AFFRC, 1990), including soil science which was considered to be a major discipline.

Environmental problems, such as eutrophication process of rivers, lakes, etc. which were associated with the application of an excessive amount of fertilizers became one of the major themes of soil science along with suitable fertilizer application to cultivate crops of high quality.

In this report the recent factors limiting soil fertility in Japan including the diversification of the food habits of the Japanese people and the decrease in the numbers of farmers as well as the problems stemming from this situation will be reviewed from the viewpoint of soil science.

1 Rotation between paddy fields and upland fields

In 1990, the Japanese government requested that 0.83 million hectares of former paddy fields be converted to cultivate other crops, for example wheat, barley, soybean, forage crops, etc. Converted paddy fields to upland fields, which account for 30% of the total paddy field area, are almost uniformly distributed in the country, regardless of the soil properties, except for the higher rate of conversion in the Hokkaido district.

Paddy fields with well-drained soils can be easily converted to upland fields unlike the paddy fields with ill-drained soils. The Hokuriku District, located in the central part of Japan and Japan sea side, is known for its ill-drained paddy fields due to the heavy clay soil and the accumulation of water from the snow melting in the spring, which hampers conversion to upland fields.

In this chapter the so called "ultra-early drainage system" which was developed in our station (Kogano *et al.*, 1989) is presented as the most difficult example of field conversion. About 10 days after perfect rooting of the rice plant, the surface water is drained and no more water is supplied to the plants until harvest. The soil moisture data are shown in Fig. 2. Water necessary for plant growth remains in the soil since the paddy fields are ill-drained even after the removal of the surface water. At the same time drying and oxidation of the

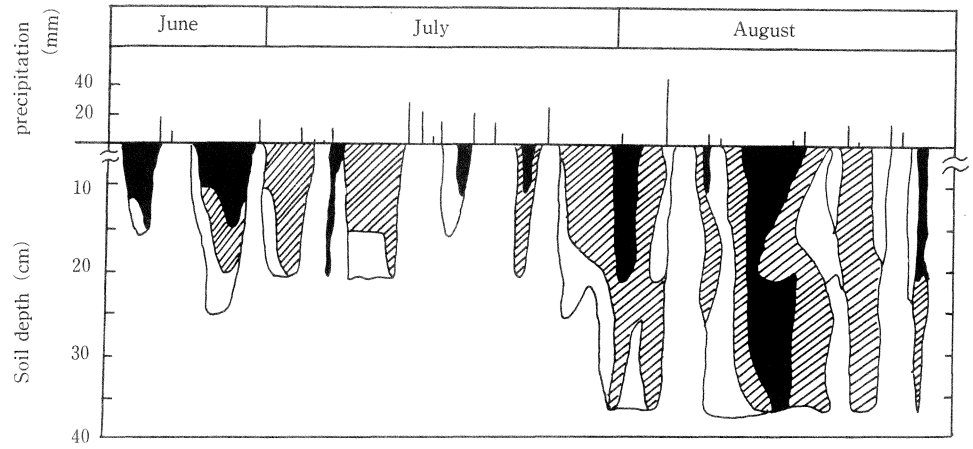

Fig. 2 Change of soil moisture of paddy field after surface water drainage. After Kogano.
□<**pF**1.5 ▨ **pF**1.5-2.0 ■ >**pF**2.0

soil which are required for the cultivation of upland crops in the following year take place. These phenomena, that is, moisture regime and oxidation of soil can be detected based on the measurement of the moisture tension and ferrous condition of the soil, respectively. Even after the removal of the surface water, the redox potential and moisture of the soil are in equilibrium and suitable for rice cultivation. At the Hokuriku National Agricultural Experiment Station, upland crops can be grown successfully by the application of the ultra-early drainage system even in the first year immediately after conversion from paddy fields. The yield of brown rice is 5.5t/ha and of soybean 4.3-4.4t/ha which is considerably higher than of crops in upland fields not subjected to rotation in this area, as a reflection of the high content of mineralized NO_3-N.

2 Salt accumulation in plastic and greenhouses

The statistics of the Ministry of Agriculture, Forestry and Fisheries in 1987 stated that greenhouses covered 810 ha and plastic houses 30,856 ha for the cultivation of vegetables.

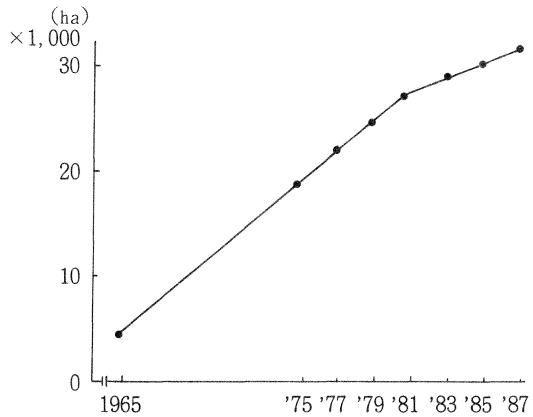

Fig. 3 Change of area of plastic and greenhouses for vegetable cultivation. Cited from Food and Marketing Bureau.

Fig. 3 in which the cultivation area of vegetables is indicated shows that the total area of plastic and greenhouses in those years had markedly increased as those structures allow the sustainable production of a variety of vegetables regardless of the season, etc. High concentration of nutrients in the soil for vegetables is generally necessary due to the low absorption of fertilizer. Also the application of a high level of fertilizers is essential to maintain the freshness of the vegetables.

However the accumulation of salts in soils of the plastic or greenhouses which stems from those practices coupled with insufficient irrigation leads to the development of physiological disorders (Ohno, 1988) of vegetables resulting in yield decrease. Presently data at the national level on salt accumulation have not been statistically analyzed. Recently, Tanimoto (1989) at Hiroshima Prefectural Agriculture Experiment Station collected data from all the prefectural agriculture experiment stations in Japan through questionnaires.

Table 1 Chemical properties of topsoil of structures and outdoor fields

	EC (1 : 5) ms/cm	AV. * P_2O_5	Exchangeable CaO	MgO	K_2O	Base sat. %
		mg/100g				
Plastic or glasshouses for the cultivation of						
Strawberry	0.27	111	306	60	56	105
Cucumber	0.75	221	478	98	113	107
Tomato	0.84	133	456	92	45	135
Eggplant	1.10	241	475	103	93	121
Leaf vegetables	0.92	207	519	88	93	151
(Average)	0.73	174	419	80	70	117
Outdoor fields						
(Average)	0.20	88	322	47	54	76

Available * P_2O_5 as Truog

Table 1 shows that the value of the electric conductivity, content of available P_2O_5, exchangeable cations (Ca, Mg, K) and base saturation percentage of the soil in the plastic or greenhouses were higher than those of soil in outdoor fields. Especially the content of available P_2O_5 in 88% of the structures exceeded 100mg/100g soil and the base saturation percentage in 90% of the structures exceeded 100%.

Table 1 also shows that there was a large salt accumulation in the soil of the structures except for those used for strawberry cultivation compared with outdoor fields. Salt accumulation induces physiological disorders in vegetables through the disruption of ion balance. Therefore, desalinization is essential, for example, through flooding of water. Also a more appropriate method of fertilizer application which is not associated with salinization should be developed in addition to the use of "cleaning crops" such as maize and sorghum.

3 Soil erosion

In Japan soil erosion does not occur frequently due to the relatively low rainfall intensity and abundant vegetation even on slopes. Recently marginal lands for the cultivation of crops of which the consumption is rapidly increasing are being reclaimed, in particular slope areas of mountains. Highlands in the central part of Kyushu which consist of Andosols are used for pastures and outdoor cultivation of cabbage and radish due to the cool climate in summer. In this area also, fields have been reclaimed recently for increasing the production of vegetables and preventing physiological disorders associated with continuous cultivation. Although Andosols are generally prone to erosion in Kyushu, most of them are reclaimed

without any measures to prevent soil erosion and recently compaction of soil by heavy machinery has brought about water erosion due to insufficient infiltration of water into the subsoil.

Iwamoto (1987) studied the effect of several methods of control to prevent erosion due to rainfall in newly reclaimed Andosol fields, standing on 8° slopes and 880m above sea level in the central part of Kyushu. In the plot with up and down ridges, which is a standard method

Table 2 Effect of ridging and organic treatments on soil erosion

No.	Treatments Ridge		Soil loss in the period June-Sept. 1982	1983	1984	1985	Total
			t/ha				
1	Up-down	-	43.9	49.1	29.2	77.4	199.6
2	Contour	-	4.9	1.8	0.7	35.3	42.7
3	Up-down	Film mulch	27.0	38.2	42.5	93.8	201.5
4	Up-down	Rye in winter	44.3	34.9	24.6	63.4	167.2

of cabbage cultivation in the area, the total soil loss (Table 2) determined between June and September during a period of four years amounted to 199.6t/ha which corresponds to a soil depth of 49.6mm. Those phenomena can be ascribed to the direction of the ridges and account for the fact that the area covered with cabbage amounts to only 20% from the months of June to July which correspond to the rainy season in Japan. However, contouring of the ridegs enabled to decrease the soil loss by 21% (=42.7t/ha) compared with the plot with up and down ridges. In the plot where stubbles and roots of rye, planted in winter, were incorporated into the soil in May, the soil loss in the following season of cabbage cultivation decreased to 167.2t/ha, even in the case of up and down ridges. Mulching with a plastic film resulted in a significant increase of surface runoff, and subsequent soil loss (201.5t/ha) between the ridges. All the treatments including plastic mulch bring about higher yields of cabbage. Pasture bands in reclaimed vegetable fields which prevented effectively soil erosion can also be used as farm roads.

4 Palatable rice

After the supply of rice exceeded the demand in Japan, farmers, farmers' cooperatives or prefectures which produce mainly rice made utmost efforts to expand the market by improving the rice quality. Japanese rice is divided into 5 grades under the Staple Food Control Act, which also determines the price of rice.

Although the quality of rice as well as that of other crops is affected by the inherent soil properties, it is considerably difficult at present to improve the crop quality by soil amelioration methods. It is generally considered that the quality of rice cultivated in Hokkaido, in particular that cultivated on peat soil is low. Rice yield in Hokkaido is similar to the national average, but only 23% of the rice production in Hokkaido corresponds to the lst grade ranking, compared to 67% for the national average (Maeda *et al.*, 1990). It is generally considered that the taste of rice cultivated on peat soil is poor due to insufficient ripening.

Hence an example of peat soil in Hokkaido which was amended by soil dressing to obtain high grade rice is presented. Inatsu *et al.*, (1978) improved the rice quality by soil dressing. Along with the increase of the amount of soil used (Table 3), the production of high grade rice (thickness>2mm), whole grain ratio, thousand grain weight, etc. increased, while

Table 3 Change of rice quality by soil dressing

	Peat soil					Clay soil
	Amount of soil used (m^3/ha)					
	0	300	600	900	1200	
High grade rice (grain %)	86.5	86.0	89.3	88.1	89.4	91.4
Whole grain (grain %)	70.1	72.4	74.5	75.2	79.1	79.7
Green rice kernel (grain %)	12.2	11.8	10.6	8.7	7.3	5.7
Opaque rice kernel (grain %)	6.6	5.5	4.7	3.8	3.5	2.4
1000 rgrain weight (g)	22.4	22.5	22.6	22.7	23.0	22.9
Maximum viscosity (B. U.) determined by amylography	3410	3680	3720	3840	3970	4030
Hardness * (1 v equivalent)	5.6	5.6	5.5	5.3	5.2	5.2
Adhesivenlss * (5 v equivalent)	1.8	1.9	1.8	2.1	2.4	2.3
Crude protein (%)	8.8	8.6	8.5	8.3	8.1	7.7

* By texture measurement

the percentage of green rice kernel, opaque rice kernel and protein content decreased. Also along with the amounts of soil used, the maximum viscosity of grain determined by amylography increased as well as the adhesiveness. Therefore soft and sticky rice, which is popular with Japanese people could be produced by soil dressing of peat fields. Rice with the same quality as that produced on non-peat soils could be obtained by using 1200 cubic meter soil/ha. Improvement of the quality of crops other than rice is also one of the main targets of soil science in Japan, for example water management, fertilization techniques, etc.

5 Impact of fertilizer application on crops and environment

Japanese agriculture is very intensive due to the small area of agricultural land available (Fig. 4) which has slightly decreased due to the decrease in the numbers of farmers, restriction on the cultivation of rice, etc. The amount of fertilizer applied per unit area (Fig. 5) is

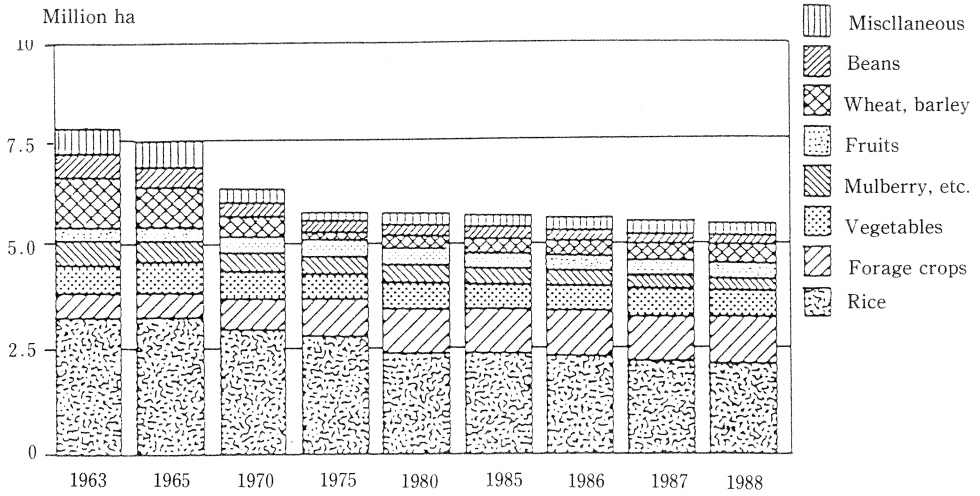

Fig. 4 Change of area for crop cultivation. Cited from Fertilizer Yearbook, 1990.

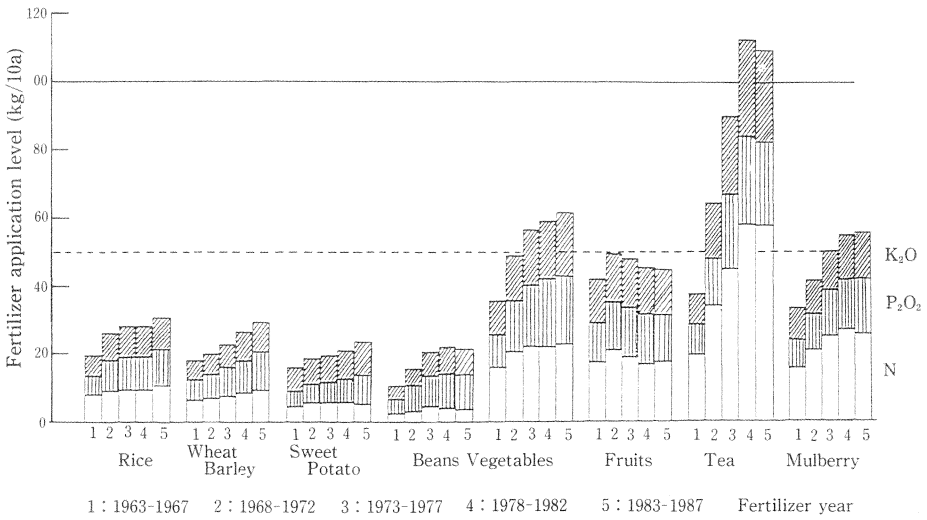

Fig. 5 Fertilizer application level for main crops (per 10a). Revised from Kitagawa 1984. Cited from Fertilizer and Machinery Division Agricultural Production Bureau.

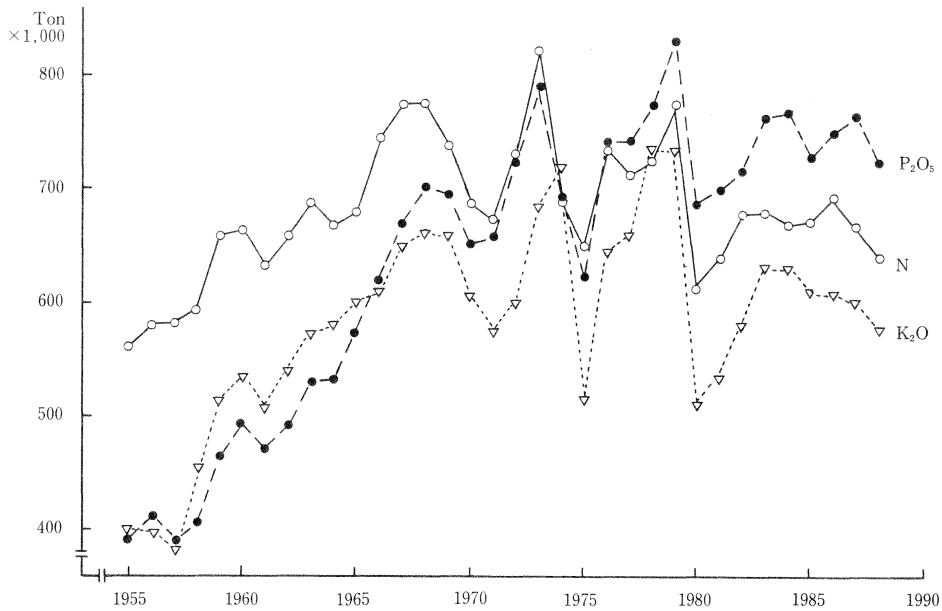

Fig. 6 Domestic consumption of chemical fertilizers. Cited from Fertilizer and Machinery Division, Agricultural Production Bureau.

increasing continuously. However, recently the domestic consumption of chemical fertilizers N, P, K (Fig. 6), has become relatively stable. On the other hand, the figures show especially that the amount of fetilizers applied per 10 a for tea, vegetables and fruits is considerably

larger than that for rice, wheat, barley, etc. This amount contributes to the increase of yield and supply of essential nutrients. However recently the concept of fertilizer application tailored to the crop requirements has tended to prevail due to the need for saving fertilizer, producing high quality crop and conserving the environment, etc.

Recently Koshino (1989) reviewed the effect of fertilization on the conservation of the

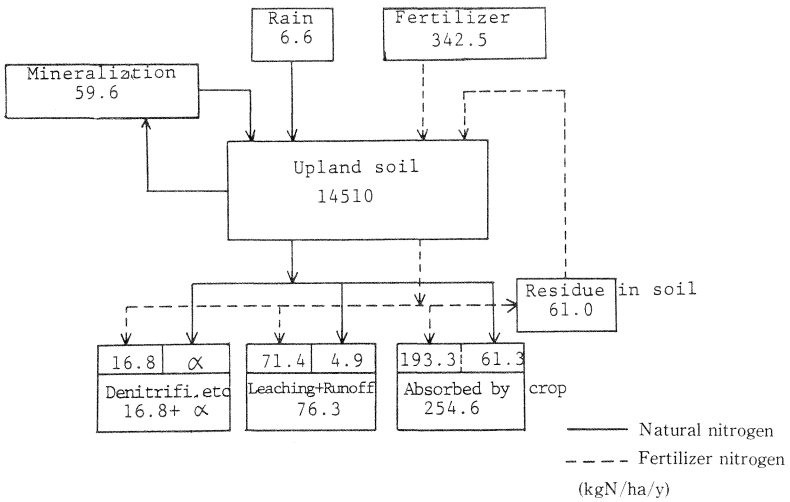

Fig. 7 Nitrogen balance in upland field. After Ogawa.

environment in rice, upland fields and tea gardens, especially based on the reports of Ogawa (1979) and Hasegawa *et al.* (1985). Ogawa's results (11) showed (Fig. 7) that 20% of 342.5kg fertilizer N/ha applied was subjected to leaching and runoff, and 25% of 595kg N/ha applied was subjected to leaching and runoff, in the case of upland fields made of Andosols. Thus the leaching and runoff of elements became more pronounced with the increase of the amount of fertilizer applied, in other words, the lceahing and runoff of components into the earth increased. Application of manure or split application of fertilizer was useful for increasing the effectiveness of nitrogen fertilizer in vegetable fields with application of large amounts of fertilizers as mentioned above. Hasegawa *et al.* (1985) reported that the amount of NO_3-N eluted from a tea garden was adsorbed into the soil of a paddy field with an equivalent area downstream. Koshino (1989) considered that the rice field acted as a built-in facility of water purification for an arable land system including rice fields.

Recently Maeda (1989) suggested the adoption of four methods of fertilizer application; (a) Fertilization matching soil fertility, (b) Fertilization for the production of high quality crops, (c) Fertilization for low cost agriculture, (d) Fertilization for conservation of the environment.

6 Changes of soil properties

During the 20 year period from 1959 to 1979, the Farmland Fertility Maintenance Project of the Ministry of Agriculture for the implementation of soil surveys of all agricultural lands was carried out with the staff of all the prefectural agriculture experimental stations. In the project 1 soil profile per 25 ha was surveyed in Japan, and about 1,100 soil maps were issued with soil analysis data. By classifying all the agricultural lands into four production capability classes (classes I, II, III, IV), it was officially recognized that the percentage of crop land with low productivity accounted for 39% of the total area of rice fields, 69% of that of

ordinary upland fields and 64% of that of orchards, etc., respectively (Abe, 1982).

At the time when the soil surveys were conducted, Japanese agriculture experienced major changes, for example, the decrease of the numbers of farmers was reflected in the decrease of the amount of manure applied into the soil. As shown in Fig. 8, only 2t/ha was applied in 1980 compared with 6t/ha in the 1960s. To analyse the changes of the soil properties, in 1975-1977 the same areas as those surveyed in the early stage of the project were re-examined. The main results (Table 4) show that the thickness and amount of organic matter of the topsoil in the paddy fields, tended to decrease, whereas the content of P and K components in the upland fields and orchards increased. Those phenomena were ascribed to

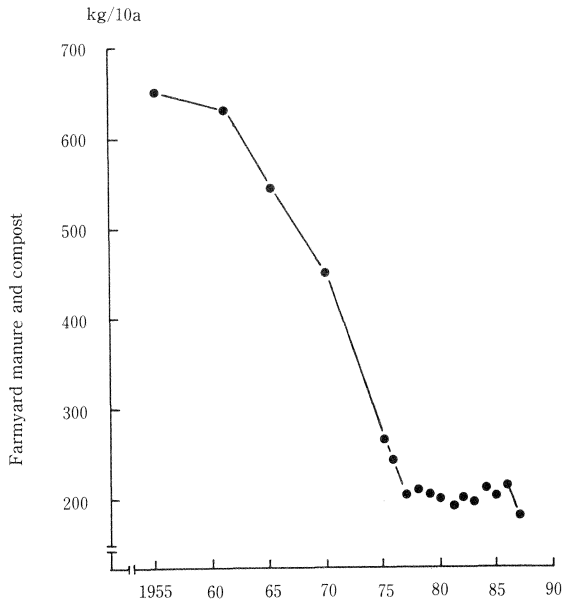

Fig. 8 Application of farmyard manure and compost into paddy field.
Cited from the Survey on Production Cost of Rice.

Table 4 Change of soil properties during the period of Land Conservation Project (expressed by the ratio of value of 1959-19689 to 1975-1977)

	Rice field	Upland field	Orchard
Topsoil depth (cm)	14.8/14.3	18.1/18.2	18.4/17.7
Hardness (mm)	12.8/11.5	12.7/12.4	14.0/14.1
Total-C (%)	2.95/2.86	4.04/4.11	2.31/2.60
Total-N (%)	0.27/0.26	0.32/0.32	0.20/0.21
CEC (me/100g)	17.5 /17.2	21.3/21.7	17.2/19.3
pH (H_2O)	5.64/5.75	5.68/5.83	5.57/5.94
CaO (mg/100g)	232/224	244/272	214/270
MgO (mg/100g)	45.9/44.6	29.4/37.0	32.7/46.6
K_2O (mg/100g)	15.5/18.0	31.2/46.7	34.0/47.9
Available P (mg/100g)	16.7/16.8	16.6/36.9	31.6/76.6

Cited from Crop Production Division, Agricultural Production Bureau.

the decrcase of the use of farm manure into the paddy fields and the increase of the amounts and frequency of fertilizer application associated with the introduction of vegetables to the upland fields.

This project has been reorganized as new Soil Conservation and Control Project by the Ministry of Agriculture, Forestry and Fisheries in all the prefectures for the continuous evaluation of the changes in the soil properties by the selection of 20,000 points of agricultural lands throughout the country for the survey. The first stage of the soil survey was carried out for all the 20,000 points in 1979-1983, the second stage also for the same 20,000 points in 1984-1988, and at present the third stage is being carried out. An interim report indicated that the trends mentioned above became more evident, especially in orchards

On the other hand, in 1976 the Ministry also initiated a new General Soil Analysis in the framework of the Soil Conservation and Control Project in all the prefectures, including 91 points in paddy fields and 68 points in upland fields and orchards. The purpose of this project is to evaluate quantitatively the changes of the soil properties in the fields designated for management of the representative soils in the areas, especially for the quantitative evaluation of the application of organic matter for soil improvement. Also the yields of the crops including yield components are recorded. The analysis of the data collected over a 8 year period since the onset of the survey by the researchers of the National Agriculture Research Center and which were stored in the data base of the computer gave the following information: (A) The effect of continuous cultivation by using only chemical fertilizers (N, P, and K) on the soil properties and the annual yields of crops, (B) The effect of continuous cultivation without nitrogen fertilizer application on the soil properties and the annual yields of crops, (C) The effect of continuous cultivation by application of organic matter on soil productivity and annual yields of crops. These effects can be evaluated based (a) on the main soil groups of arable lands in Japan, (b) kinds of organic materials applied, (c) regions, (d) kinds of crops and cropping systems. By continuing to input the yearly data into the data base, these results are likely to indicate the changes in the current soil productivity and to contribute to estimate future changes. Also these data may indicate the threshold of soil productivity by the application of only chemical fertilizers or the absence of nitrogen fertilizer application and the upper limit associated with the application of organic matter.

For the preservation of the agro-social environment, the Soil Productivity Improvement Law was enacted in 1984 to (a) establish guidelines for the improvement of the soil properties and countermeasures, (b) designate areas for improvement due to the poor soil properties, (c) standardize the soil improvement materials, etc. Moreover in 1989 the Organic Farming Office was established in the Ministry.

All these projects, laws, etc. aim at the development of sustainable agriculture in Japan and the supply of safe foods by soil improvement.

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Discussion

Verapattananirund, P. (Thailand): The rate of compost application decreased sharply from 8t/ha in 1960 to 2t/ha in 1980. Why did the hardness of paddy soils decrease while that of upland and orchard soils increase?

Answer: At present rice straw is semi-automatically put on the surface of paddy fields at harvesting time. This straw contributes to offset the increase of soil hardness. On the other hand, the difference in hardness between upland fields and soils of orchards is very small and not significant.