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Water Resources in Relation to Major Agro-Environmental Issues in Japan

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Although Japan is well known as an industrialized country rather than an agricultural one, agriculture is treated as a very important sector from cultural and environmental perspectives. Only 15% of Japan's land is suitable for cultivation, but the agricultural economy is highly subsidized and protected. With per unit area crop yields among the highest in the world, the agriculture sector still dominates the major part of water use (65%) in Japan followed by domestic and industrial uses (20% and 15%, respectively). Like many other monsoon Asian countries, rice is the staple food in Japan, and paddy fields and terraces are often referred to as the country's cultural and environmental indicators. This paper outlines the conditions of water resources and their relations to some major agro-environmental issues in Japan as well as focuses on a case study research related to soil erosion in the southernmost part (Okinawa Island) of the country. The case study results show that if farmland soil is mixed with the plant residues and treated for 3 to 4 months under natural conditions, the hydraulic conductivity of the soil can be improved and eventually reduce the amount of soil erosion.

Key words: water use, water pollution, surface runoff, soil erosion, agro-environment, agro-ecosystem

Introduction

Agriculture plays a significant role in the world in achieving sustainable development because of its importance to food supply and the social structure of rural areas, as well as its impact on nature and the environment. Depending on the region/country, these different aspects are weighted differently. As for Japan, the country's agriculture, although tiny but often termed as an outstanding contributing sector to the country's economy (1.5% of GDP), is characterized by high production and secured subsidies because of Japan's socio-cultural background and environmental characteristics. The relatively wet climate dominated by monsoons provides the country with considerable freshwater supplies. The general reliability of the precipitation patterns, coupled with Japan's extensive network of rivers is used for irrigation, making possible extensive wet-rice cultivation. For the last two decades, the country has paid much attention to its water resource management as well as agricultural and environmental aspects. However, some natural and man-made agro-environmental disasters associated with water (use and quality), land (use and management), agro-ecosystems, agro-biodiversity, global warming, etc. still remain as major problems to be solved. This paper reviews some major agro-environmental issues in relation to water resources management in Japan. The main objectives of the paper are to:

- ○ Introduce the present status of water resources, such as precipitation, rivers & lakes, and water withdrawal rates in Japan;
- ○ Review the linkages between water and some major agro-environmental issues, such as non-point source pollution, soil erosion, ecosystem and biodiversity;
- ○ Highlight a case study in the southern part of Japan;
- ○ Outline limitations and analyze future trends of water resources and their relation to agro-

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environmental ecosystems from a local perspective.

The first half of the text of this review paper is composed of the information and data available in recent publications, while the second half describes a case study and provides analytical comments.

Climate and Geographical Factors

Japan consists of a great string of islands in a northeast-southwest arc that stretches for approxi mately 2,400 km through the western Pacific Ocean. The country has a total land area of 377,887 square km. Nearly this entire area is taken up by the country's four main islands; from north to south these are Hokkaido, Honshu, Shikoku, and Kyushu. Honshu is the largest of the four, followed in size by Hokkaido, Kyushu, and Shikoku. In addition, there are numerous smaller islands, the major groups of which are the Ryukyu (Nansei) Islands (including the island of Okinawa) to the south and west of Kyushu and the Izu, Bonin (Ogasawara), and volcano (Kazan) islands to the south and east of central Honshu. Approximately 70–80% of the country is mountainous. The mean annual precipitation is 1,740 mm (approx.), ranging from 800 mm (approx.) in the north of Hokkaido Island to 3,600 mm (approx.) in the south of the country. Most parts of Japan are within the North Temperate Zone with four seasons a year. Though Japan would appear to have plentiful water resources, it is so densely populated that the annual amount of per capita rainwater is only 5,100 m^3 which is about one-fourth of the world annual average (22,000 m^3/capita). Moreover, this amount varies significantly with area and time.

Water Resources in Japan

Rivers, Lakes and Reservoirs

In Japan, there are more than 2,700 river basins. Among them, 109 rivers are designated as being managed by the central government in principle because of their major importance to the economy and to the protection of the environment. The catchment area of these Class A rivers covers approximately 239,900 km^2. Class B rivers consist of the other rivers which are managed at the local level (prefecture government level). Average surface water resources are estimated at 420 km^3/year. There are 247 freshwater aquifers underlying a total area of 69,130 km^2. The renewable potential of groundwater resources is estimated at 27 km^3/year, but because of the steep slopes a significant part (estimated at 17 km^3/year) probably returns to the river systems. Where land subsidence, saline intrusion and excessive lowering of the water table have occurred, groundwater use has been restricted to a safe yield by applying legal regulations and ordinances to critical areas. The total annual renewable water resources are estimated at 430 km^3/year.

More than 600 lakes are scattered among the seaside districts and the volcanic zones. The major lakes in the country are:

- Biwa lake, which lies in the inland basin near Kyoto in central-west Honshu with an area of 674 km^2 and a water volume of 27.5 km^3;
- Kasumigaura lake, which is close to the mouth of the Tone-gawain with an area of 220 km^2 and a water volume of 0.848 km^3;
- Inawashiro lake, which is a lake created after a volcanic eruption in northwest Honshu with an area of 104.8 km^3 and a water volume of 3.86 km^3.

The history of dams and reservoirs in Japan dates back many centuries, and a number of ancient earthen dams are still used for paddy irrigation. Since the 1920s, technological advances have led to the construction of dams and weirs with modern designs, and these have contributed mainly to irrigation development and hydropower generation. The construction of large-scale multipurpose dams including flood control began in the 1950s to meet increasing water demand for municipal and industrial use as well as irrigation. In 1993, there were 2,556 dams over 15 m high in service for water supply, hydropower generation and flood control with a total effective storage capacity of 16.5 km^3. In addition, 587 dams under construction at that time were planned to provide 7.7 km^3. The total storage capacity of all these dams is approximately 29 km^3. A 1990 survey showed that another 4.8 km^3 were provided by small dams. In 1996, the installed capacity of all power plants in operation was 226,994 MW of which 21,171 MW or 19 percent was hydropower.

Water Use in Agriculture

Agriculture holds the major part of water use in

Japan (65% of the total water withdrawal). Water for flooded rice paddy fields and fish culture comprises most of Japan's agricultural water use. Water use for agriculture has recently been flat nationwide with a slight decrease in rice paddy irrigation offset by an increase in irrigation for other crops. Irrigation of rice paddies, which takes up the largest portion of agricultural water usage, dropped only slightly in spite of decreased rice paddy acreage, partly because of the increased water use per unit area in paddies and the lower rate of recycling due to the digging of separate canals for irrigation and drainage. Demand for water in rice paddies is seen from mid-April through September with peaks during tillage before the crop is transplanted and in the season after midsummer drainage. Water use during tillage in particular has risen recently. There is a small demand for water during seasons other than the ones mentioned above, for secondary crop farming and crop rotation. Irrigation for other types of crops is expected to continue to increase because the area land with access to irrigation is increasing and in many cases, agricultural chemicals and fertilizers are mixed with the water that is used to irrigate these fields. The supply or water to green-houses has particularly increased steadily in recent years, and their growing popularity has increased the demand for water in winter.

Water usage in livestock farming is expected to continue to increase because of the growth in the number of livestock. Aquaculture is also growing, although it accounts for a small portion of all agricultural land. Water culture, which is a form of liquid culture, is the main form of liquid culture in terms of total area. Irrigation channels have traditionally served several functions in agricultural areas, such as supplying water to wash crops and agricultural machinery, and fire protection and preservation of the rural environment. To maintain and promote the use of such functions, various approaches are being taken in the improvement of irrigation channels, including construction of recreational areas with trees and shrubs planted along irrigation channels.

Major Issues Concerning Water and Agro Environment

As it can be understood from the above information, to maintain the standard of quality, secure the required quantity, and manage such a vast amount of fresh water used in agricultural purposes, it is very important to maintain different related agro-environmental components in sustainable ways. In this section, the author focuses and discusses some major agro-environmental problems associated with water resource management, namely non-point source pollution from agricultural fields, rainfall erosion and their effect on aquatic ecosystems and biodiversity in the southern part of Japan.

Non-Point Source Pollution

Water quality is a major environmental issue. Japan's aquatic environment has improved significantly over the last few decades, because industrial water pollution was sharply curtailed. However, the environmental quality standards for organic water pollution are still not being met in approximately 30% of Japan's total water area. Pollution from non-point sources is one of the single largest remaining sources of water quality impairments in Japan. Agriculture is a major source of several non-point source pollutants including nutrients, sediment, pesticides and salts that deteriorate the water quality in rivers and oceans, causing eutrophication in lakes and reservoirs.

Although there is no general laws encompassing all aspects of water resources management in Japan, specific aspects related to water resources management are regulated by legislations such as the Water Pollution Control Law (updated as of 1996), the River Law (updated as of 1997), the Land Improvement Law (updated as of 2001), the Water Resources Development Law (updated as of 1983), etc. Such laws have been effective to solve specific land and water pollution problems. But when different types of pollutants come from different non-specific sites especially where farmers and non-farmers live alongside each other in agricultural and rural communities, it becomes a difficult job to solve practically.

Scientists in Japan have recently suggested approaches and models for proper watershed management to reduce the non-point effluents to the rivers and lakes. Kato *et al.,* (2004) assessed the non-point outflow loads to Kasumigaura Lake for the past 10 years, and developed a material cycle evaluating system that can reduce the total nitrogen load to the lake by up to 40%. Funakawa *et al.,*

(2004) developed another water quality model based on the study of non-point effluents to Biwa Lake and Noda Lagoon. Tada *et al.,* (2006) reviewed different models to estimate the effluent loads from watersheds, and focused on the uncertainties of hindered non-point sources. According to the water quality researchers in Japan including Tada (2006), a model based official program, for example, the TMDL (Total Daily Maximum Load) program in the USA, would be effective to reduce effluents from watersheds to the water basins.

Soil Erosion

The outflow of topsoil from farmlands mainly due to water and wind are termed soil erosion in agriculture. In Japan, soil erosion has not been a serious problem for the last few decades except in some parts of the country. Northern areas including Hokkaido and the northeast region (Tohoku Region) are slightly vulnerable to wind erosion followed by water erosion. However, since the country does not have a distinct dry season and most of the farmlands are well reclaimed, wind erosion in Japan is an issue of merely local importance. Rather, water erosion caused by rainfall has been a long time problem (since 1972) in the southern part (Okinawa Island) of Japan. The island's annual rainfall is much higher than the country's average annual rainfall. Moreover, farmland soils (Kunigami Maji, Shimajiri Maji, Kutcha etc.) are mostly clayey, and so vulnerable to erosion. In addition, pineapple and sugarcane are the common crops cultivated as the main cash crops in the island. Both these cropping fields are by nature (ridged and furrowed) susceptible to erosion. In past years, many studies (Onaga *et al.,* 1978–1984, Gibo *et al.,* 1984) have been carried out that have encouraged the local government to introduce a policy named 'Red soil pollution monitoring' in 1985. Until today, the monitoring system is in progress, but has achieved little in practice. Further researches have been done by researchers (Onaga *et al.,* 1990, Gibo *et al.,* 1994, Kusaka *et al.,* 1998, Yoshinaga *et al.,* 2000) to find different technologies to prevent soil erosion from farmlands. Researches are still continuing for this subject but if we look at the history and the present status of red soil erosion in Okinawa, the suggestions of researchers have not always been welcomed by the local farmers because of many locally oriented socio-cultural and traditional backgrounds (Matsumoto and Roy, 2004). The situation indicates the necessity to do more research to find ways that can be accepted by the local farmers. In other words, when planning research a pre-feasibility study is a must where local farmer opinion gets priority.

Agro-Ecosystem and Biodiversity

Especially, in Japan, conservation of biodiversity and ecosystems in agriculture has been an important issue for agricultural and environmental policies since 1999, when a changed agricultural foundation law by the Japanese Government and European Union (EU) stimulated progress. Rice paddy fields ecosystem is treated as the most important agro-ecosystem and biodiversity indicator in Japan. According to the literature, approximately 2,000 species of plants and animals associated with rice paddy fields have been recorded in Japan (Hidaka 1998). This biodiversity in species richness can be regarded as a general characteristic of the rice paddy ecosystem. Kobayashi *et al.* (1973) examined in detail the biodiversity of arthropods using sweeping methods in rice paddies of several sites of Tokushima Prefecture in the late 1950s. More than 450 species of insects, spiders and mites were recorded. Kasahara (1947) examined a list of rice paddy weed specimens in 25 prefectures in Japan and recorded 174 plant species. However, nowadays, if we had a chance to examine arthropod fauna in the same fields, it may be difficult to collect the same diversity of species in rice paddies as in the 1950s (Hidaka 2004). Such a decreasing tendency of different natural habitats and species in the rice field ecosystem in Japan is apparently derived from rapid urbanization, steady production level maintenance and other factors.

Environmental Degradation by Surface Runoff —A Case Study in Okinawa Island—

Okinawa is Japan's southernmost prefecture and consists of hundreds of islands in a chain over 1,000 km long where Okinawa Island is the largest one. Okinawa has a humid subtropical climate with an annual rainfall ranging from 2,000 to 2,500 mm.

The rainfall erosivity is very high and the dominant soils (commonly termed as red soil) are highly erodible causing the loss of valuable topsoil from the farmlands as well as polluting the ocean water. Most of the red soil particles (mostly silt and clay) carried to the sea by rivers and or canals are deposited on semi enclosed reef moats adjacent to the coast, and often the red soil is repetitively stirred up by turbulence induced by typhoons and monsoons. The water then becomes cloudy and the soil is distributed over the reefs and causes decay. The deterioration of the coral reef along with other environments of aquatic species as a result of eutrophication and pollution from increasing sedimentation has already been reported. Coral reefs, which offer shelter to small reef animals in their three-dimensional spaces, are said to hold the largest number of species per unit area on earth so when corals die out and the three-dimensional space decreases the numbers of fish and other organisms also eventually decrease. The central and local governments have introduced several techniques such as establishment of green belts, infiltration tanks, sedimentation tanks, underground drainage, and uses of different soil improvers, coagulants, mulches as well as evaluation and monitoring systems for measuring red soil outflow. However, improvements are not progressing as satisfactorily as expected. The reason is that many local factors other than technological aspects are involved in the red soil erosion process in Okinawa. However, farmers and policy makers agree that — 'not to let the soil go out of the fields is the best way to overcome the situation'.

For the last few years, the author has been carrying out field surveys and experiments in parts in Okinawa to find technologies that can be accepted by the local farmers. In this section, I will introduce the results of a case study to improve the hydraulic conductivity of red soil treated with different waste materials. As also mentioned in the above section of soil erosion, most of the Okinawa's farmland soils are clay and silt with poor hydraulic conductivity. When raindrops strike the surface, the surface soil creates a crust that also hampers infiltration. As a result, surface runoff takes the topsoil out of the field. Therefore, to increase the infiltration rate would help decrease the surface runoff. A preliminary survey was carried out to determine the extension of technology among the farmers in Okinawa. The survey helped us to make a decision to grasp the present conditions of conservation works in Okinawa's farmlands and search for possible materials locally fit. In most of the sugarcane and pineapple fields, farmers use the plant residues as organic mulch. This practice helps to maintain the soil moisture as well as to minimize the effects of raindrops to some extent. However, when heavy and concentrated rainfall occurs, the mulching materials themselves are also washed out from the fields. Therefore, while planning the experiments, we targeted more efficient ways to use the plant residues so that they could contribute to improvement of the soil structure (by humification) and accelerate the infiltration rate. Discarded fired pottery, a common traditional item, were also used as experimental materials. The materials were processed in our laboratory. The processed materials were then mixed at different ratios with the sampled red soil (Kunigami Maji soil), and the mixture (only sugarcane residue-mixed samples) placed in an artificial atmospheric chamber (Fig. 1). The temperature and the humidity of the artificial atmospheric chamber was set to conditions similar to Okinawa (30 degrees Celsius and 60% humidity). In short, the materials (sugarcane plant residues and fired pottery) were ground with a small grinder, and then mixed with different ratios of soil (soil: fired pottery = 1 : 0.01, soil: plant residues = 1 : 0.05, by weights). Then the mixed soil samples with plant residues were placed in the

Fig. 1. Artificial Atmospheric Chamber

artificial chamber for 1 month, 2 months, 3 months and 4 months. Observations were carried out regularly and the changes in organic matter content (%), porosity (%) and soil aggregation were measured for each soil sample. Column tests (Fig. 2) were performed to investigate the hydraulic conductivity (cm/s) for each treated sample and the thickness of crust (mm) was also measured. From the results, the best conditions for using the local materials were determined. The results (Fig. 3 and Fig. 4, Table 1 and 2) of the experiments indicate that a small amount of ground sugarcane plant residues mixed with the red soil could increase the infiltration rate that can eventually decrease the surface runoff. Such a treatment can easily be performed under natural conditions in any Okinawa farmland just by making a hole at one corner of the field and filling the hole with the ground residues. It is noted here that while apply-

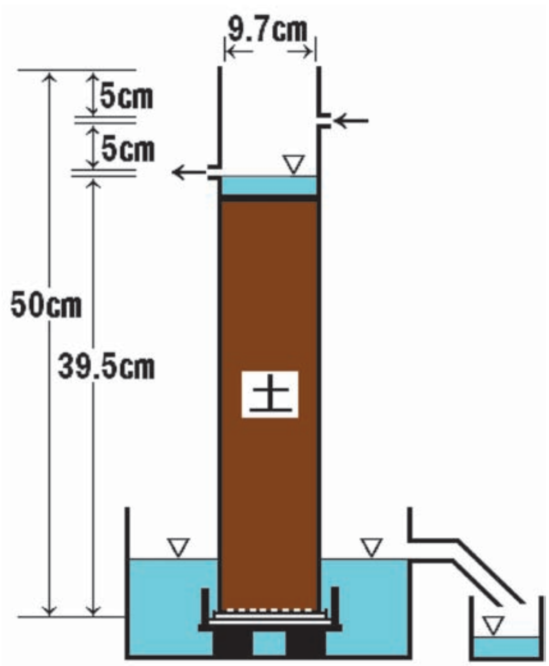

Fig. 2. Hydraulic Conductivity Test Apparatus

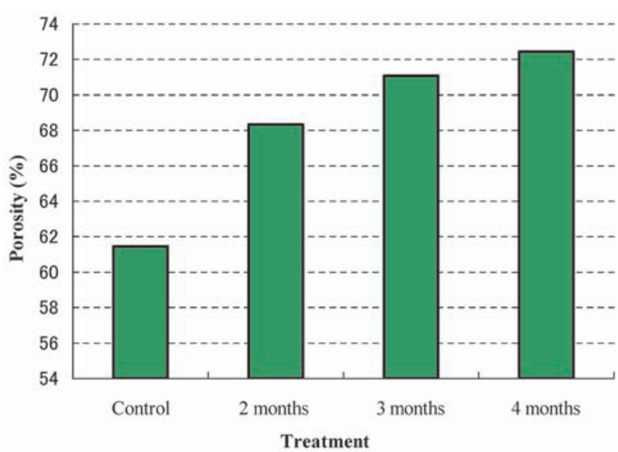

Fig. 3. Comparison of Porosity (%)

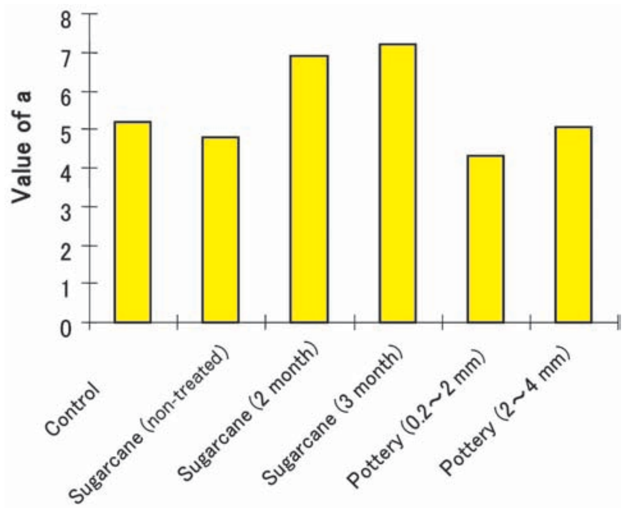

Fig. 4. Comparison of Hydraulic Conductivity (cm/s) when hydraulic conductivity $k=a\times10^{-4}$ (Darcy's Law)

Table 1. Organic Matter Content (%) in Treated Soil

Treatment period (Plant residues+Soil)	OMC (%)
2 months treatment	6.62
3 months treatment	6.63
4 months treatment	7.56

Table 2. Crust Formation in Each Sample

Sample	Thickness (mm)
Control	3.4
Sugarcane (non-treated)	2.5
Sugarcane (2 months treated)	1.5
Sugarcane (3 months treated)	1.6
Sugarcane (4 months treated)	1.5
Fired potteries (0.2～2 mm)	2.1
Fired potteries (2～4 mm)	2.5

ing the treatments to the practical farmlands in Okinawa, we realized a machine to perform the grinding operation at a large scale needs to be designed.

Conclusions

While many of the Asian countries are still struggling to provide the basic needs to their people, factors such as population, poverty, education, and technology are not issues in Japan. The Japanese Government and its Ministries are doing a lot of research and extension work within the country and providing various materials, incentives and programs to help people understand the current state of the agro-environment and water resources. Japan is one of the leading countries in the world now trying to improve the environment and overcome water problems. The country hosted the Ministerial Conference on the occasion of the 3rd World Water Forum in 2003. The 'Kyoto Protocol' was highly appraised by groups concerned about the environment throughout the world. However after that, the speed to eradicate the existing and remaining tasks as mentioned in this review paper is not notably rapid as compared with the speed of industrialization and economic development of the country. Why? In my opinion, many other factors such as socio-cultural, traditional, after-effects of modernization are correlated with resource management and environmental issues. Some of them are presented here.

Recently (2003), the Japanese Government adopted a policy to establish a sound hydrological cycle in various areas such as forests, agricultural land, rivers, water-supply and sewerage systems. Five ministries (Ministry of Health; Ministry of Agriculture; Ministry of Economy; Ministry of Land, and Ministry of Environment) have been engaging in consultative meetings in order to share related information and promote deliberation on comprehensive measures. The Guidelines for Establishment of Sound Water Cycle (2003) was developed to clarify the basic direction for identifying the factors that cause water-related issues by evaluating the overall water cycle, and dealing with the problem. The policy is undoubtedly a good step. However, as also suggested by many researchers in Japan, still no efficient model or program like TMDL (Total Maximum Daily Load) program (in USA) was included in the government policies and laws that could assess and more efficiently prevent non-point effluents from any particular spot were not developed.

As for soil erosion problems in Okinawa, few pre-feasibility studies have been carried out on the local farmers' attitude before introducing technologies to prevent farmlands from soil loss. Agriculture and farming works are labor-intensive. In Okinawa, most of the farmers prefer to produce sugarcane and pineapples because the lands are suitable for these crops and the farming operations and land management are less labor intensive. In addition, no other major alternative crop has been shown to be more economically feasible there. Replacing the existing traditional farming system/crops by merely a technologically-better way is impractical in Okinawa. Therefore, to extend any new method to the farmers, locally fitted research should be given priority.

There are many reports and media on the recent food habit changes of young Japanese. Western foods, fast-foods that do not essentially use rice materials are becoming popular and the consumption of Japanese rice is gradually decreasing. Moreover, the young generation is losing fascination for agriculture. Naturally, the paddy field area is declining in recent years. Labor shortage is so acute that the Japanese Government is considering to import foreign labors for agriculture (Asia Times, Dec 3, 2003). In Japan, where rice paddy fields are the main indicator of the agro-environment and ecosystem, a paddy-less Japan will bring many new environmental problems.

Besides, there are other problems associated with water and the agro-environment that still remain to be solved, such as construction of dams, land consolidation, river head works, global warming, etc. Whenever any of these technical matters become a problem in any locality, and is focused on in the mass media, rather than technical, many socio-cultural, political and traditional factors are in the headlines. Why are not such factors considered at the basic stage of planning and designing a technological approach?

Finally, every short coming of eco-environmental problems associated with water and agriculture cannot be eradicated completely (100%) because the total ecosystem is made up of many known and unknown sub ecosystems and factors. However, in a highly developed country like Japan where the government and people are careful, resource management and maintenance of eco-environment can be achieved to the best level.

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