Global Warming and Sustainable Agriculture

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Abstract

Flooded rice fields are an important source of atmospheric methane (CH_4). This paper discusses the factors that influence CH_4 production and emission from the source and potential methods of mitigating CH_4 emissions. The use of the mitigation option suggested could potentially decrease CH_4 emission from flooded rice fields by about 40% worldwide.

Then, this paper indicates that modern science has developed superior mechanisms for the use of rice paddy fields and that they display multiple functions for environmental conservation. Finally, I show future trends for sustainable agriculture, land use system and the global environment. In one example it is shown that technologies for both improving soil fertility and mitigation of CH_4 emission in rice paddy fields contribute to the promotion of sustainable agriculture.

Introduction

Human activities are closely related to the changes in the Earth's environment. The cycle of materials on a global scale has been transformed as a result of the clearing of forests for increasing the arable land area, expansion of the livestock industry, changes in the chemical composition of the atmosphere by the combustion of fossil fuels, discharge of wastes, cutting through mountains for mining deposits and distribution of heavy metals on the Earth. Mankind is now modifying the original environment of the Earth.

The biosphere of the Earth is suffering from environmental disruption including global warming, depletion of the ozone layer, deforestation, marine pollution, air pollution, acid rain, deforestation, water pollution, soil erosion, pollution with metals, reduction of biological diversity, pollution through nuclear wastes, pollution through livestock and human wastes and depletion of underground water.

Environmental limits have also been reached in the agriculture, forestry and fisheries industries. Productivity in a large number of existing farmlands has been reduced though new arable lands can not be found easily. The production of food has recently been reduced by deforestation, overgrazing, excessive fishing, salinization of soils and desertification. Water resources in many regions have been depleted and contaminated. Agricultural production and urban water resources will be strictly limited in the future.

Agricultural activities themselves, through the increase of food production, affect the environment. Nitrous oxide derived from the application of nitrogen fertilizers and from livestock wastes and methane produced from flooded rice fields and ruminant livestock affect the atmosphere and cause global warming and destruction of the ozone layer.

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However, the beneficial effect of agriculture on the environment should not be overlooked. The Committee for Agriculture of the OECD suggests that agriculture is a major custodian of the environment and is endowed with multiple functions to conserve the environment. Sustainable agriculture is proposed as one way to solve the conflicting problems. However, this concept is controversial and complicated in its definition and in the application of practices to attain sustainability.

As an example, it is suggested that paddy field farming in delta areas covered with alluvial soils rich in nutrients or in fertile lowlands, valleys, terraced lands with volcanic ash and other soils is a most suitable system to promote sustainable agriculture and preserve the agro-ecosystems, provided that the availability of water resources is not a limiting factor. Under such conditions, moderate yields of rice can be continuously obtained by using relatively low input due to the superior functions of paddy fields associated with submergence, including nitrogen fixation by algae, phosphorus dissolution and availability to crop under reductive conditions, increased soil pH under reductive conditions, potassium and silica availability by hydrolysis, enhancement of microorganism activity, buffer action from micro-climate change, nutrient enrichment from irrigation water, prevention of weed growth, N_2O absorption from the atmosphere, and absence of growth injury in spite of cropping for 1,000 and 2,000 years.

In addition, the role of paddy fields in the control of soil erosion and runoff, preservation of soil fertility, cycling of nutrients, reservoir function, etc. should be emphasized.

How can we maintain and increase food production and control the above load on the environment? In this paper, I report the role of rice paddy fields in the promotion of sustainable agriculture and conservation of the environment. First, the factors influencing CH_4 production and emission, an estimation of the global emission rates of methane and the methodology to reduce CH_4 emission from rice paddy fields are presented.

Then, the superior functions of rice paddy fields as a natural industry with a history of more than one thousand years of food production are presented. Further, modern science has developed superior mechanisms for the use of rice paddy fields and rice paddy fields display multiple functions for environmental conservation.

Finally, I outline future trends for sustainable agriculture, land use systems and the global environment, and one example in which technologies for both enhancing soil fertility and mitigation of CH_4 emission in rice paddy fields contribute to the promotion of sustainable agriculture.

Methane flux from flooded rice fields

The concentration of atmospheric CH_4 has been increasing since the Industrial Revolution (Khalil and Rasmussen, 1981 ; Steel *et al.*, 1987 ; Blake and Rowland, 1988). Methane has a strong influence on atmospheric chemistry (Thompson and Cicerone, 1986). Methane is also an important greenhouse gas for the climate system because of its infrared absorption spectrum (Wang *et al.*, 1976). A rapid increase, therefore, could have significant environmental consequences (Ramanathan *et al.*, 1985). Although a slowing down of the growth rate of atmospheric CH_4 has been reported recently (Dlugokencky *et al.*, 1994), there are large uncertainties in the global budget of CH_4 and its changes. Therefore, further research is needed to estimate the accurate strength of individual sources and sinks of atmospheric CH_4. Additionally, it is essential to reduce CH_4 emissions from anthropogenic sources.

Of the wide variety of sources for atmospheric CH_4, rice paddy fields are considered to be an important source (Climate Change 1995) because of the recent increase in the rice harvested area worldwide (IRRI, 1991). Field measurements indicate that a number of agro-environmental factors, including soil properties, plant activities, cultivation practices, and climatic factors, are combined and influence CH_4 emission from rice paddy fields (Conrad, 1989; Yagi *et al.*, 1994; Minami, 1995).

1 Factors affecting CH_4 production

Measurements performed at various locations of the world show that there are large temporal variations of CH_4 flux which differ with the soil type, application of organic matter and mineral fertilizer (Minami, 1995). These variations also indicate that the CH_4 flux is critically dependent upon several factors including climate, characteristics of soil and paddy, and agricultural practices. On the other hand, about 90% of the world's harvested area of rice fields is located in Asia with India and China accounting for 60% of the total. Therefore, we need more detailed information about CH_4 flux values in Asia.

The main processes that occur in flooded soils consist of a series of successive oxidation and reduction reactions mediated by different types of microorganisms. Flooding alters the character of the microbial flora in soils by decreasing O_2 concentration. Fermentation is one of the major biochemical processes responsible for organic matter degradation in flooded soils. The main products of the fermentation process in flooded soil are ethanol, acetate, lactate, propionate, butyrate, H_2, N_2, CH_4 and CO_2. The latter three gases usually contribute to the largest proportion of the gas phase of flooded soils.

The major pathways of CH_4 production in flooded soil are the reduction of CO_2 by H_2, with fatty acids or alcohols as hydrogen donors, and the transmethylation of acetic acid or methyl alcohol by methane-producing bacteria (Takai, 1970; Conrad, 1989). In paddy fields, the kinetics of the reduction processes is strongly affected by the composition and texture of soil and its content of inorganic electron acceptors. The period between flooding of soil and the onset of methanogenesis varies with soils.

The redox potential (Eh) directly controls the production of CH_4 in soils. The Eh of the soil gradually decreases after flooding. Takai *et al.* (1956) and Yamane and Sato (1964) showed that CH_4 was not emitted from flooded paddy soils until the Eh fell below-200 mv. There is a correlation between the soil redox potential and CH_4 emission (Patrick *et al.*, 1981; Cicerone *et al.*, 1983; Yagi and Minami, 1990). Fig. 1 shows the seasonal variations in CH_4 emission, the daily mean soil and air temperature, and the soil Eh in Ryugasaki paddy fields (Yagi and Minami, 1990). The period of CH_4 emission from the paddy fields corresponded closely to the period of low redox potential in the paddy soil.

Substrate and nutrient availability is also an important factor. Fig. 1 shows that the application of rice straw to paddy fields significantly increases CH_4 emission compared with the application of compost prepared from rice straw or chemical fertilizer.

Temperature is an important factor controlling the activity of soil microorganisms. Yamane and Sato (1961) found that CH_4 formation reached a maximum value at 40℃ in wa-

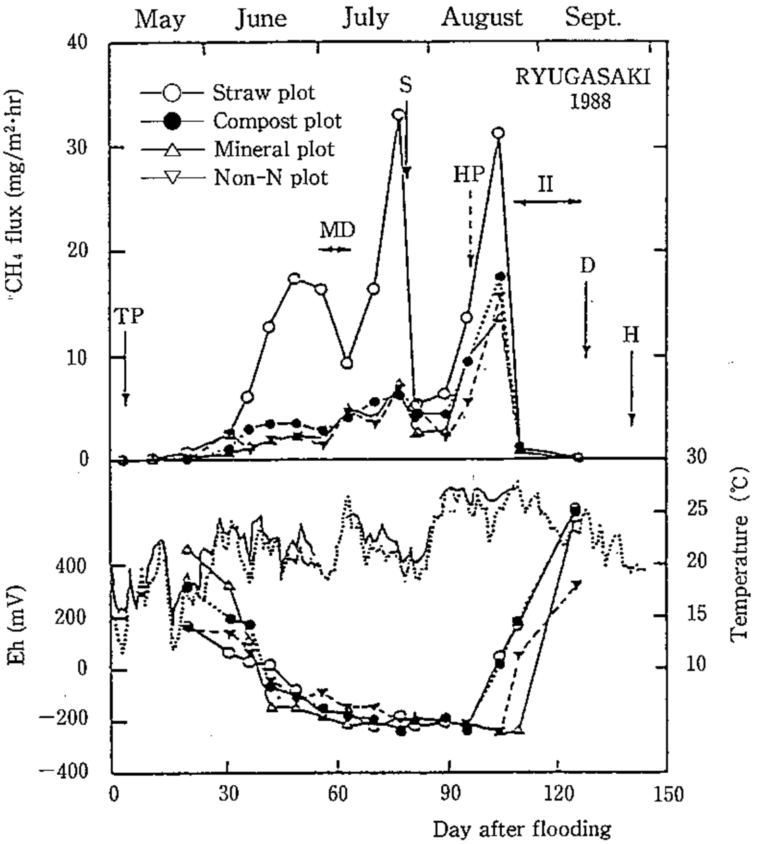

Fig. 1 Seasonal variations of the CH_4 flux, and daily mean temperature of soil and air and soil Eh at four depths in a Japanese paddy field (Yagi and Minami, 1990)

terlogged alluvial soils. At above 40℃, CH_4 formation decreased and stopped at 60℃. A negligible amount of CH_4 was produced below 20℃.

It is generally recognized that most CH_4 is formed in a very narrow pH range around neutrality (6.4 to 7.8). Following flooding, pH of acid soils increases, and pH of alkaline soils decreases. The pH increase in acid soils is mainly due to the reduction of acidic Fe^{3+} to $Fe^{2}+$.

The addition of sulfate as chemical fertilizer to flooded soils also influences the production of CH_4 because it increases the redox potential, and the H_2S production is toxic to methanogens. Also, the addition of sulfate increases the activity of sulfate-reducing bacteria which outcompete methanogens for substrate. Sulfate must be reduced before CH_4 can be formed in paddy soils (Takai, 1980).

The addition of fertilizer nitrate to flooded soils may also suppress the production of CH_4. Since nitrate acts as a terminal electron acceptor for anaerobic respiration in the absence of molecular oxygen it fixes the redox potential of soils at certain values so that the activity of strict anaerobes is prevented (Minami, 1995).

2 Methane emission and oxidation

There are three mechanisms for the transfer of CH_4 from rice paddies to the atmosphere. Methane loss as bubbles from paddy soils should be a common and significant mechanism. Diffusion loss of CH_4 across the water surface is another process. The third most important phenomenon is the transport of CH_4 through aerenchyma. Release to the atmosphere through the shoot nodes which are not subject to stomatal control, is generally the most important emission mechanism accounting for more than 90% of the total CH_4 emission from rice paddies (Minami, 1994). During the course of the rice-growing season a large portion of the CH_4 produced in the flooded soil is oxidized before being released to the atmosphere (Sass *et al.*, 1992).

Although CH_4 flux rates are a function of the total amount of CH_4 in the soil, the gas may be consumed in the thin oxidized layer close to the soil surface and in deep flood water. It is known that soil methanotrophic bacteria can grow with CH_4 as their sole energy source, and that other soil bacteria consume CH_4. As a small amount is dissolved in water, CH_4 is also leached to ground water.

Fig. 2 illustrates the balance between emissions of CH_4 from flooded rice fields as a result of CH_4 production, oxidation, and leaching to groundwater (Minami, 1994). The quantity of CH_4 emitted from a rice field depends upon several factors, including soil factors, nutrient management, water regime and cultivation practices.

3 Estimates of CH_4 from rice production

Of the wide variety of sources for atmospheric CH_4, flooded rice fields are considered to be important because of the 75% increase in the rice harvested area in the world since 1935. The harvested paddy rice area has increased from 86×10^6 ha in 1935 to 148×10^6 ha in 1985. However, in the last few years, the rate of expansion of rice-growing areas has decreased. About 90% of the world's harvested area of rice paddies is located in Asia. Of the total harvested area in Asia, about 60% is located in India and China.

Climate Change 1992 (1992) estimated the global emission rate from paddy fields to range from 20 to 150 Tg/yr, averaging 60 Tg/yr, or about 5–30% of the total emission from all sources. These estimates were mainly based on the field measurements of CH_4 flux from paddy fields in United States, Spain, Italy, China, Australia and Japan. There were no detailed data available to estimate CH_4 flux from India and China in 1990, but recently some data have been published for Asian countries (e.g. Minami *et al.*, 1994).

Sass (1994) tightened the range of projected CH_4 emissions from a review of CH_4 studies in China, India, Japan, Thailand, the Philippines and the USA. He combined the data on total area of rice paddies with the flux estimates published in various chapters of the book of Minami *et al.* (1994) to produce Table 1. By extrapolating these data to the world rate, Sass (1994) estimates that the total CH_4 emission from rice fields ranges between 25.4 and 54 Tg/yr. The greater value is consistent with Climate Change 1992 (1992) estimate of 60 $TgCH_4$/yr, but the range indicates that the actual rate may be lower.

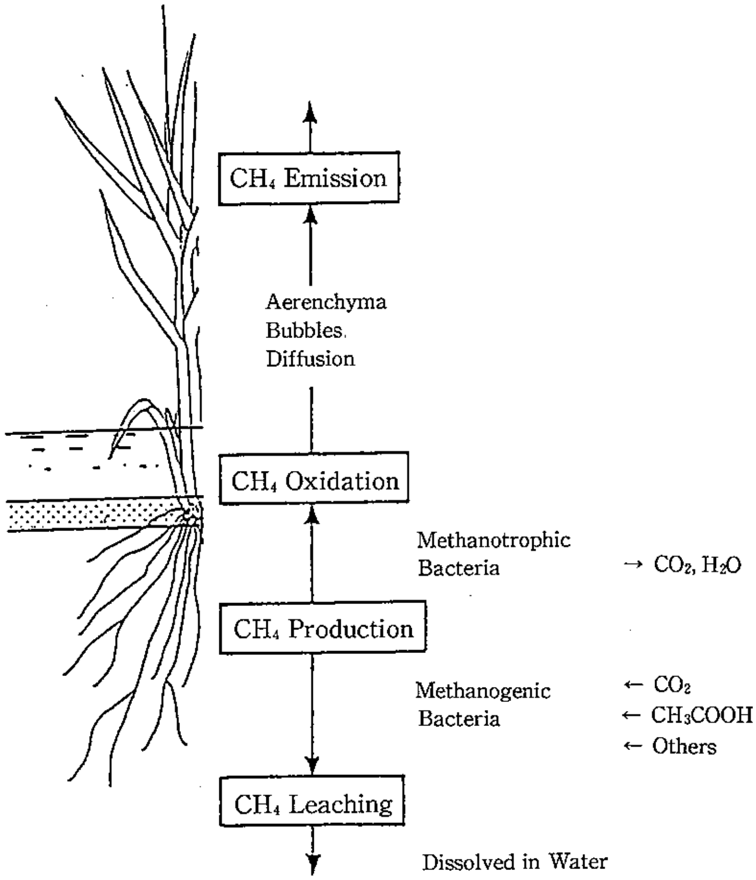

Fig. 2 Diagram of CH_4 production, oxidation, emission and leaching (Minami, 1994)

Table 1 Estimates of CH_4 emissions from rice fields of different countries as presented in Minami *et al.* (1994) and an estimate of global CH_4 emission from rice (Sass, 1994)

Country	Total area of rice paddies (1,010 m^2)	Total rice grain yield (Mg)	CH_4 emission (Tg/yr)
China	32.2	174.7	13-17
India	42.2	92.4	2.4-6.0
Japan	2.3	13.4	0.02-1.04
Thailand	9.8	19.2	0.5-8.8
Philippines	3.5	8.9	0.3-0.7
USA	1.0	6.4	0.04-0.5
Total	91.0	315.1	16-34
World Total	147.5	473.5	25.4-54.0*

* World total emission rate obtained by area scaling of the total emission rates measured in the paper presented in Minami *et al.* (1994).

4 Methane oxidation in soil

Ojima *et al.* (1993) estimated that landuse changes during the past 200 years have decreased the global temperate soil sink for CH_4 by 20–30%. Reeburgh *et al.* (1993) estimated that the global aerobic soil sink was about 40 TgCH_4/yr. From a review of available CH_4 uptake data, Minami *et al.* (1993) limited the total terrestrial CH_4 consumption to 7 and 78 Tg/yr. Thurlow *et al.* (1995) showed that unflooded paddy soils, after drainage practices, are able to act as a sink of CH_4 and vary in their ability to consume CH_4 depending in the soil temperature and atmospheric CH_4 concentrations.

Options for mitigating CH_4 emission

1 Strategies

Based on the processes involved in the control of CH_4 emission from rice paddy fields, it is concluded that the possible strategies for mitigating CH_4 emission from rice cultivation include control of either production, oxidation, or leaching processes. Since methanogens re-

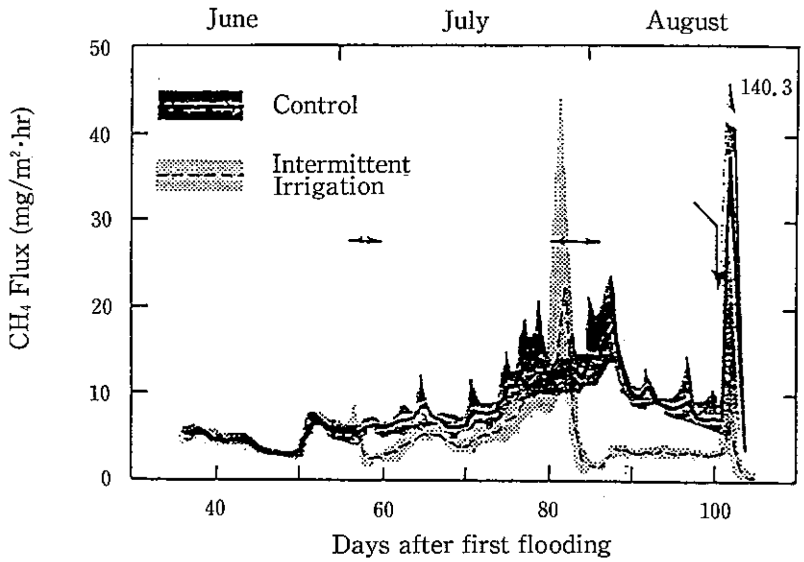

Fig. 3 Effect of water management on CH_4 emission from a rice paddy field

Effect of water management on CH_4 emission from a paddy field
←→ : periods without paddy water on the intermittent plot
↓ : timing of final drainage

Source: Ryugasaki auto-flux system, 1991 quire highly reducing conditions for their activity, arresting the development of soil reduction is one of the most effective methods of decreasing CH_4 production rate in soils. This can be accomplished by aerating soils during the flooding period by altering water management, or by inhibiting the progression of the sequential redox reactions by the addition of chemicals. Changing tillage may lead to the same effect on soil reduction. These options may simultaneously enhance CH_4 oxidation rate in soils. Reducing the amount of labile organic matter in soils by composting of organic fertilizer or promoting aerobic decomposition of biomass is another effective way of controlling CH_4 production in soils. Since rice plants also contribute significantly to the production/oxidation of CH_4 in the rhizosphere and its transport to the atmosphere, selection of rice varieties that emit a small amount of CH_4 may also be effective to mitigate CH_4 emission from rice paddy fields (Yagi *et al.*, 1997).

2 Water management

Methane emission is influenced by the type of water regime used on a rice field, especially by the duration of the flooding period and the drainage schedule. Draining the rice field during the growing season seems to decrease CH_4 production by increasing the state of oxidation of the paddy soil (Sass *et al.*, 1992).

Short-term drainage had a strong effect on CH_4 emission as shown in Fig. 3 (Yagi *et al.*, 1996). A large flush of CH_4 emission was observed in the intermittently drained plots immediately after each drainage. Total emission rates of CH_4 during the cultivation period were 14.8 and 8.63 g/m^2 for 1991 and 9.49 and 5.18 g/m^2 for 1993 in the continuously flooded and intermittently drained plots, respectively.

The rate of water percolation in rice paddy fields also exerts an influence on CH_4 production and emission, because water percolation influences chemical conditions in flooded soils. A lysimeter experiment showed that the CH_4 emission rates significantly decreased with the increase in the percolation rates (Yagi *et al.*, 1990). Total emission during the cultivation period ranged from 5.7 to 13.8, from 0.6 to 4.8, and from 0.1 to 0.3 g/m^2 in the no, moderate (about 5 mm/day), and high (about 20 mm/day) percolation plots, respectively.

3 Soil amendments and mineral fertilizers

Sulfate is one of the most promising candidates for this strategy because it is commonly used as a component of mineral fertilizer and soil amendment. The addition of sulfate to soil activates sulfate-reducing bacteria which decrease the activity of methanogens by restricting the availability of substrates in submerged soils.

Lindau *et al.* (1993) reported that CH_4 emission can be decreased by adding sodium sulfate (28–35%) or coated calcium carbide (36%) with urea compared to urea alone, and by using ammonium sulfate (20%) instead of urea.

Addition of other oxidants, iron-containing materials such as bauxite, iron ore and residues of iron manufacture probably reduce CH_4 emission.

4 Organic matter management

In world's rice cultivation, fresh organic matter is often applied solely or after being mixed with rice straw. In the fields, a part of the biomass of previous crops and weeds remains in soils at the start of rice cultivation. Such organic matter is decomposed in soils and acts as an electron donor and a substrate of fermentation reactions. Therefore, organic matter management has a significant effect on CH_4 production in soils. The management of organic matter in rice cultivation is also important from the viewpoint of sustaining soil fertility. This organic matter management option for mitigating CH_4 emission is deeply related to sustainable agriculture afterwards.

Many researchers demonstrated that the incorporation of rice straw and green manure into rice paddy soils dramatically increases CH_4 emission. A field study showed that the incorporation of rice straw in soil at rates of 600–900 g/m^2 after previous harvest increased CH_4 emission rates by 1.1-to 3.5-fold in Japanese rice paddy fields, while application of rice straw compost slightly increased CH_4 emission (Yagi *et al.*, 1997). These results clearly indicate that composting of fresh organic matter significantly mitigates CH_4 emission from rice paddy fields.

5 Others

Methane emissions vary greatly with rice varieties (Sass and Fisher, 1994). Selection for CH_4 emission potential as well as productivity and taste may be a useful strategy for mitigating CH_4 (Lin *et al.*, 1994 ; Neue, 1992). Sass and Fisher (1994) surveyed 10 rice cultivars that are adapted to temperate and subtropical irrigated fields and found that seasonal CH_4 emission rates varied from 18 to 41 g/m^2.

Certain methods of tillage, seeding and weeding used to minimize water use and mechanical soil disturbance may also offer some CH_4 mitigation potential (Neue, 1992). Choice of rice cultivar and types of chemicals and the placement of fertilizer can affect the activity of CH_4-producing bacteria and hence the emission of CH_4. For example, the substitution of wet tillage and transplanting of rice seedlings with dryland tillage and dry seeding seems to reduce CH_4 emissions. Minimum tillage should have similar effects. Avoidance of mechanical soil disturbance during weeding may also reduce CH_4 emission.

6 Estimates of CH_4 emission reduction in rice production

The three major management options that have been suggested for limiting CH_4 emissions from rice are (1) water management, (2) nutrient management and (3) cultural practices and use of new cultivars. Combination of these practices for global rice production could lead to large decreases in CH_4 production in rice. In Table 2, some potential CH_4 reduction ascribed to specific management practices is outlined (Mosier *et al.*, in press).

Table 2 Estimates of effect of management practices on CH_4 production in flooded rice (Mosier *et al.*, in press)

Mitigation practice	Production amenable to mitigation	Potential decrease	Range
	Tg CH_4		
Irrigation management	50	5	3.3-9.9
Nutrient manegement	50	10	2.5-15.0
New cultivars and other cultural practices	50	5	2.5-10.0
Emissions amenable to mitigation	50	20	8.0-35.0

Superior functions of rice paddy fields

Modern science has confirmed the superior function of rice paddies. To maintain high yields and to secure continuous harvests every year on arable land, we have to add large quantities of chemical fertilizers. When such large amounts of fertilizers are applied to arable land, salt damage occurs in both soils and plants. However, in rice paddy fields, there are no such problems because paddy soils are flooded during the hot summer season. As a result, the soil in rice paddies shows the following superior characteristics.

1 Nitrogen fixation by algae

Algae occur when paddies are filled with water. Algae absorb the ammonium nitrogen derived from soil, and fix it in the paddies as organic nitrogen. As a result, discharge of nitrogen in water can be prevented. In addition, some algae can fix the nitrogen in the air.

2 Effective use of nitrogen through the application of lime

Since quick lime and slaked lime are alkaline, when used in rice paddies, the pH levels of water temporarily reach a value of about 9. As a result, humus in the soil is dissolved making it easier for microorganisms to break it down, and thus, in turn the supply of ammonium nitrogen increases.

3 Phosphorus solubilization under reduction conditions

Phosphorus is an essential element for crops. In rice paddy soils, phosphates occur in the form of ferric phosphates. When reduced, the iron in ferric phosphates changes from ferric iron to ferrous iron. As a result, the solubility of ferric phosphates is significantly increased, and iron is dissolved in the water and absorbed by the roots of rice. In addition, when reduction causes the pH level to increase, the ferric phosphates become even more soluble.

4 Increase of soil pH under reduction conditions

Since the soil in rice paddies is constantly covered with water, when it is dried, the pH level becomes acidic. When it is covered with water, iron and carbon gas increase the pH level. This is why the acidity of the soil is not a problem.

5 Potassium and silica solubilization by hydrolysis

Rice absorbs silicic acid to such a degree that it is referred to as a silicic acid plant. Even if potash and silicic acid are not supplied as fertilizer, rice will grow normally. This is because the elements in the soil undergo hydrolysis.

6 Activity of microorganisms

The soil of rice paddies is highly fertile because algae in the water produce organic matter, and are constantly supplying that organic matter to the soil. After the algae die, the nutrients assume an inorganic form and are supplied to rice in later stages, or in the following year. Photosynthetic bacteria decompose hydrogen sulfide and organic acids that are harmful to rice. Aerobic and anaerobic microorganisms interact at an appropriate level, and the microorganisms are used by the ecosystems.

7 Nutrient enrichment from irrigated water

Irrigated water from upstream contains magnesium, calcium, silica, potassium, nitrogen and other nutrients, as well as clay particles, all of which supply nutrition to rice paddy soil. In recent years, however, there has been an excess of these nutrients which is harmful to rice.

8 Buffer action against micro-climatic changes

By covering rice paddies with water, a certain alleviating effect on sudden changes in temperature that occur seasonally or at night is observed.

9 Ability to withstand continuous cropping

Problems arising from continuous cropping are related to microorganisms such as molds that require oxygen and nematodes. Since rice paddies are covered with water, the amount of oxygen is insufficient for these organisms to thrive, so that continuous cropping for even thousands of years is possible.

10 Ability to control weeds and pests

Since it is difficult for weeds and pests that require aerobic conditions to thrive, the conditions are more favorable than those in upland fields.

Environmental preservation functions of agricultural ecosystems

Living organisms exert an "environment-forming effect". Although living organisms are affected by their ambient environment, they, in turn, affect and create a unique environment.

In areas in which agriculture and forestry activities are conducted, the effects of the atmosphere, soil, water, plants and animal create such a unique environment. These effects exert environmental preservation functions when they are beneficial for nature and human beings. This is how we define environmental preservation functions of agricultural ecosystems in this paper.

Many agricultural scholars have suggested that mining and industry destroy nature, but that agriculture protects it. However, it is clear from the book entitled "Topsoil and Civilization" by V. G. Carter and T. Dale (1955) that agriculture has also destroyed nature. The fall of Mesopotamian civilization resulted from the accumulation of salt in the soil that led to desertification. Starting with Europe, there are many other such examples around the world.

Such phenomena gave rise to the concept of protection of nature in Europe and United States. Because Japan's land is so naturally resilient, we have not recognized the importance of protecting nature. Regarding rice paddy agriculture, however, the wisdom of our ancestors has helped us, as I have explained earlier. Rice paddy agriculture has enabled to overcome the disadvantages of Japan's natural conditions, and allowed us to produce food while preserving the natural environment. In addition, our ancestors developed agricultural technology by maintaining a harmony with the grasslands and farms in mountainous and woodland areas, and flat lands with rice paddies, hence utilizing the toposequence in nature.

The Japan's Ministry of Agriculture, Forestry and Fisheries has implemented many projects to quantitatively assess the multiple functions of agricultural and forestry ecosystems and to develop a management technology to maintain and improve these functions (Minami, 1993). As a result of these projects, it was confirmed that agricultural and forestry ecosystems exert various beneficial functions.

In this paper I will focus on the functions of rice paddy fields which can be outlined as follows.

1 Water conservation function

In this function, soils and rice plants absorb water and replenish water resources, such as underground water. This function can be quantitatively assessed through annual rainfall, land inclination, land use, soil permeability, water permeability of the surface layer, water-holding capacity of the surface layer, and underground water level data.

2 Flood prevention function

Water is temporarily stored in paddies and reservoirs to prevent floods. This function can be quantitatively assessed based on surface layer geology, land inclination, topography, land use, soil and annual rainfall data. One example shows that rice paddies are about four times more effective than mountainous or woodland areas in the prevention of floods and about 15 times superior to urban areas.

3 Water quality improvement function

Microorganisms in rice paddy soils and in irrigation and drainage canals help to clean water polluted with nitrogen and phosphorus. This function can be assessed based on denitrification potential, vegetation absorption, regional categorization, surface soil layer, toposequence, river and water movement vector data.

4 Landslide prevention function

This function prevents landslides in the case of terraced rice paddies and crops planted on inclined fields. This function can be quantitatively assessed based on valley spacing, inclination, soil layer depth, tree age, tree type and farmland type data.

5 Soil erosion prevention function

This function prevents wind and water erosion of soil. This function can be quantitatively assessed based on rainfall, land inclination, land use, soil type, and soil particle size data.

6 Biodegradation of organic wastes

In this function livestock manure, urban garbage and sewage are decomposed. This function can be quantitatively assessed based on average annual temperature, annual rainfall, soil texture, inclination, and land use data.

7 Conservation of biotic communities

This function enables to preserve living organism resources such as insects, small animals and birds. Rice paddy agriculture called "secondary nature" preserves various types of plant life, and the living organisms which are dependent on it. Quantitative assessments are currently being conducted.

8 Air quality conservation function

By this function harmful gases in the air are absorbed, leading to purification of the air. Convection and diffusion cause harmful gases in the air, such as nitrogen and sulfur, to be absorbed by agricultural and forestry ecosystems. Rice paddies even have the ability to absorb nitrous oxide in the air which is related to global warming and destruction of the ozone layer. Quantitative assessments will be conducted in the future.

9 Health and recreation functions

Paddy fields as well as forests, grasslands and farmlands exert health and recreation functions for visitors. These functions are assessed based on data such as convenience, scenery, history, cultural importance, and existence of water.

10 Amenity

The term amenity covers several functions. Therefore, each agricultural or forest area should concentrate on the preservation of specific functions. By categorizing the structure of agricultural and forest areas, and assessing the various functions of each category, the relative importance of the functions in each category should be determined. These functions can be assessed based on data from geological categories, land use categories, vegetation, and questionnaires.

11 General characteristics of environmental preservation function

The methods listed above can be used to assess individual environmental preservation functions. A radar chart method for the display of general characteristics has been developed to design environmental plans.

12 Others

Agricultural and forestry areas also enable to maintain greenery resources, provide places of rest for urban residents, preserve cultural aspects, and cultivate artistic tendency.

Future trends

In order to achieve sustainable agriculture, a sustainable land use system must be developed. The development of such a sustainable system will only be possible if it does not exceed the delicate balance of material circulation necessary for agriculture and forestry. In order to develop such a system, it goes without saying that ecological principles will have to be applied. Due to the deep concern about the global environment, the development of sustainable land utilization systems is the best method for both advanced nations and developing nations for environmental conservation. The problem, however, is whether a new balance can be established to offset man-made impact, such as the increase in the population. This is why ecological principles are needed. It is our duty to clarify the ecological principles that will support sustainable land use systems by actually developing such systems in different regions and countries, and comparing these at an international level.

Based on the functions of paddy fields, paddy field agriculture in Japan and Asia will have to take a different approach from the corporate agriculture practiced in countries such as the United States. In order to enhance the environmental conservation functions of agriculture and implement sustainable agriculture, land use will have to be rationalized in regional units, material circulation will have to be as complete as possible within each unit, and balance must be maintained. To this end, the exodus of mountain farming communities, and the disorderly use of land where urban and rural areas meet must be revised.

We must show the concerned parties that continuing sustainable agriculture such as paddy field agriculture which aims at conserving the local environment, will, in the end, lead to conservation of the entire earth. If we understand paddy field agriculture in this way and develop our country's agriculture accordingly, this will indicate that we are thinking globally, and acting locally. If paddy field agriculture is to be considered in this way and Japan's agriculture is to be developed accordingly, it will be necessary to consider this on a global scale and act locally. The methane that is produced from paddy fields, however, has a profound relationship with global warming. Developing a technology to control the production of methane is also very important in promoting sustainable agriculture. This is a good example of how environmental conservation is closely linked with sustainable agriculture. For example, the application of rice straw compost compared with raw rice straw is not only increasing soil fertility, but also decreasing methane emission from rice paddy fields. This finding indicates that the technologies for the enhancement of soil fertility and mitigation of CH_4 emission in rice paddy fields contribute to the promotion of sustainable agriculture.

Furthermore we must identify other technologies for sustainability of rice paddies based on cropping systems, water management, cultivation practices and rice varieties.

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