SUSTAINABLE AGRICULTURE TO CONSERVE WATER ENVIRONMENT IN JAPAN

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ABSTRACT

Agriculture is multifunctional itself, and agricultural innovations should also contribute to the environmentally-sound agriculture. In 1999, the Japanese government enacted three laws concerning sustainable agriculture in order to make it more environmentally sound. Items in the laws which aim at the reduction of agricultural impact on the environment include farming techniques to reduce fertiliser and pesticides, financial support to farmers who implement the environmentally-sound agriculture, and sufficient treatment of livestock waste. As every land use has different effects on the water environment, that is, paddy fields and wetlands can effectively remove nitrogen (N) from strongly contaminated water, and upland fields can be serious N pollutant sources, to construct the N flow from upland fields to paddy fields should be effective to reduce N load outflow from the agricultural catchment. Further, to construct recycling systems for agricultural drainage and domestic effluent within rural areas are effective to contribute the water environment conservation. These measurements require upgrading of water management infrastructures and management system. In addition, to compensate farmers for reductions in agricultural productivity due to the environmentally sound agriculture should be considered an important factor in achieving the sustainable de-velopment of agriculture.

Keywords: multifunctionality of agriculture, eco-friendly agriculture, natural cyclical function of agriculture

INTRODUCTION

Agriculture is multifunctional. Agriculture plays public roles, for example, the conservation of national land, water resources and the natural environment, and the formation of a good landscape as well as the maintenance of cultural tradition. The multiple roles, in addition to its conventional role as a primary food supplier, should be fulfilled sufficiently for the future to maintain the stability of people's lives and the national economy.

Figure 1 shows a conceptual structure for contribution of agriculture to national development. Agriculture plays such roles through stable production in rural areas. In consideration of the importance of its conventional role as a primary food supplier as well as its multifunctional roles, the sustainable development of agriculture should be promoted by securing a workforce and agricultural facilities, including the necessary farmland and irrigation/drainage system, establishing a desirable agricultural structure based on regional characteristics with an effective combination of these elements, and maintaining and improving the “natural cyclical function of agriculture” which is defined as the “natural cyclical function” as the function of agriculture in stimulating the biological and physical cycle in nature while being influenced strongly by the cycle (MAFF, 1999). Practically, the agricultural measurements are holistically undertaken with four aspects, which are securing the economy, the environment, the irrigation and drainage facility, and residents in agricultural areas. The measurements are strategically implemented on agriculture and rural

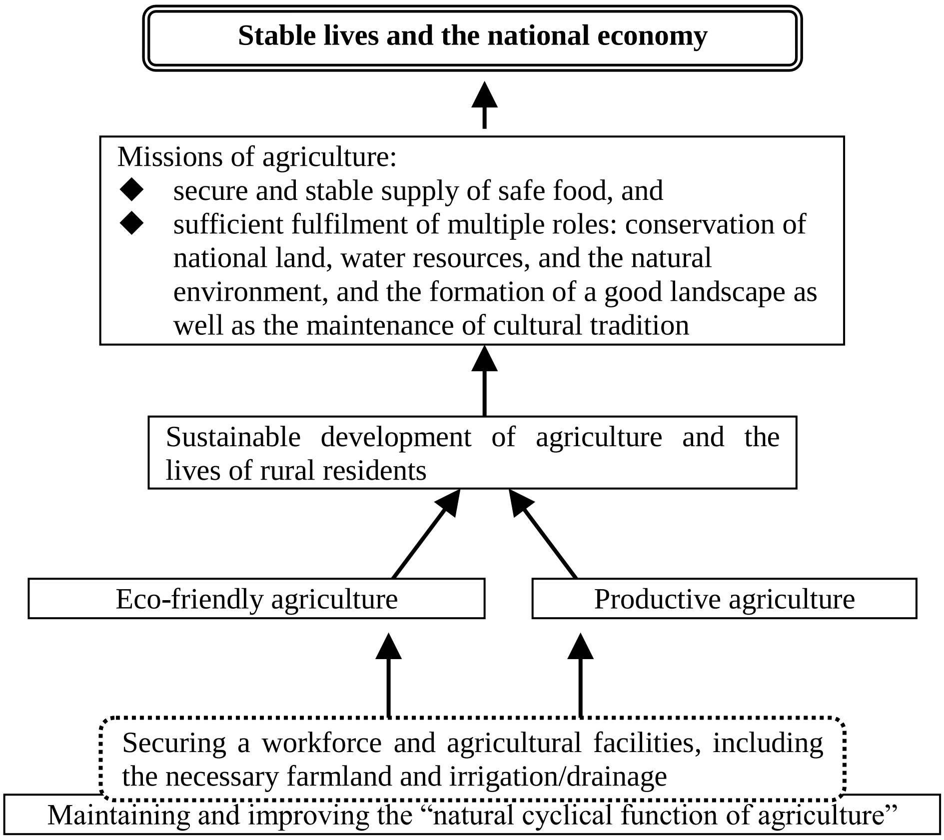

Fig. 1 Structure of the roles of agriculture.

Table 1 Measurement to be implemented from in respect to the holistic approach.

	Areas where agriculture is much multifunctional but economically disadvantage.	Areas where agriculture is economically advantage but less multifunctional.
Economy	Compensation for economically disadvantage over in flat areas.	Fostering economically strong agriculture.
Facilities	Everyday maintenance by farmers.	Maintenance by land improvement district.
Environment	Fertilisation by manure with reduction of chemical fertilisers and pesticides.	
Residents	Condition ordering for people settlement and rural-urban exchange.	

improvement depending on the conditions in every agricultural area, typically, agriculture is much multifunctional but economically disadvantage in the intermediate and mountainous areas, in contrast, agriculture is economically advantage but less multifunctional in flat areas, as summarised in **Table 1**. The precise measurements should be implemented to develop merits and advantage of the area, nevertheless securing farmers and residents in rural area is essential all over the place. Moreover, environmentally-sound agriculture is also essential and strongly requested by the nation and the world market, and foods produced by a highly environmentally-sound agriculture, which could be often comparatively payable in the economically disadvantage area, have a special value.

In what follows of this paper, the relationship of agriculture to water environment is briefly introduced based on recently studies conducted in Japan, and further action needed to achieve the sustainable development of agriculture is discussed.

AGRICULTURAL IMPACT ON THE ENVIRONMENT

Nutrients in cultivated land

Figure 2 shows changes in the demand for fertiliser over time, and the area of cultivated land including paddy fields and upland fields in Japan (MAFF of Japan, 2004). From 1950 to 1970 there was a rapid increase of approximately 3×10^5 t in the demand for nitrogen (N) fertiliser, whereas the area of cultivated land decreased by approximately 2×10^6 ha. Consequently, the demand for N fertiliser per unit area of cultivated land doubled or trebled in the period. The demand for phosphate fertiliser (P_2O_5) and potash fertiliser (K_2O) per unit area also doubled. Since 1970, the demand for N fertiliser per unit area changed in line with the change in the area of cultivated land, and remains at around 180 kg ha^{-1}. On the other hand, the demand for P_2O_5 and K_2O per unit area has slightly decreased since 1980.

Based on the statistics supplied by MAFF (2004), yields of rice, wheat and soybean per unit area have increased steadily, and yields of vegetables and pasture have remained at 3,800 kg ha^{-1} and 2,800 kg ha^{-1}, respectively since 1970. The only slight decrease in the last 30 years has been in the yield of fruit. As we have only scanty information on the overall farmland production, it cannot be proved that crop yields have increased through these fifty years, but it seems likely.

The fact that crop yields have increased without a corresponding increase in the use of fertiliser in these twenty years is due to innovations in agricultural technology, such as farming technique, agricultural mechanisation, land improvement and breed improvement. In this sense, the innovations in these technologies after 1980 have contributed to the reduction of the impact of agriculture on the water environment.

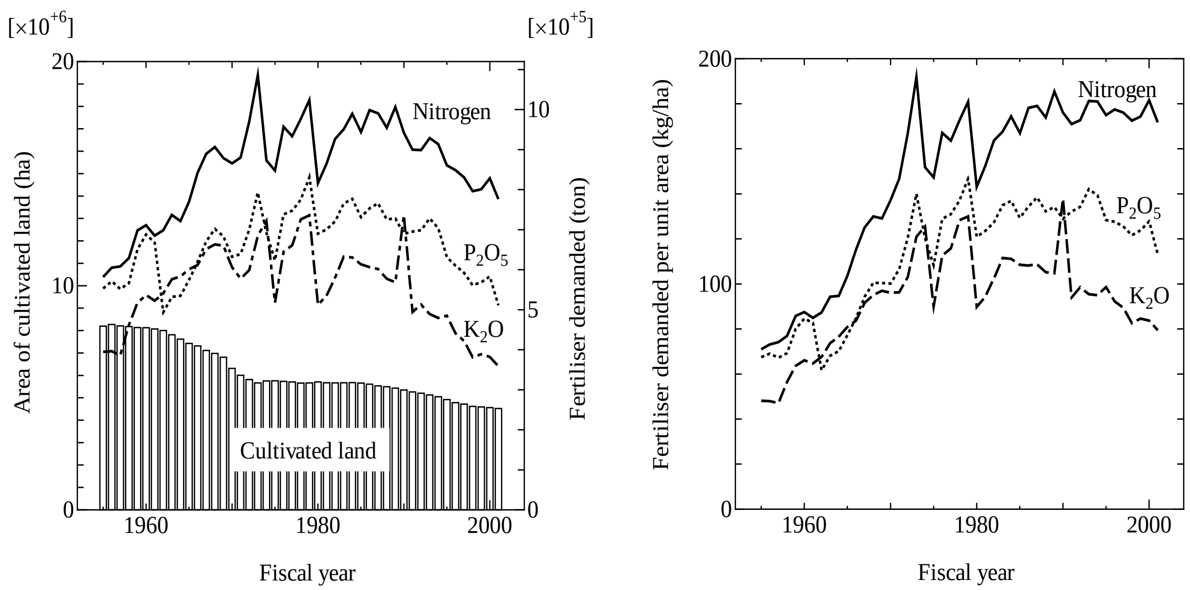

Fig. 2 Changes over time in (a) the demand for fertiliser and the area of cultivated land and (b) the fertiliser per unit area of cultivated land.

Nutrients in livestock farming

Further agricultural impacts on the environment are caused by livestock farming. Livestock may cause pollution of surface water and groundwater, and odour problems. Ammonia emission from livestock waste may cause air pollution.

Figure 3 shows changes over time in the numbers of livestock and the N load produced from them in Japan. Livestock farming was developed after 1950. There was a rapid increase in the number of pigs raised, reaching 12×10^6 head in 1988, which was six times the number in 1960. The number of cattle raised also increased, but not so rapidly. After 1990, the numbers of pigs and cattle began to decrease. The amount of N load produced from livestock farming changed with the number of raised livestock, and doubled during the thirty years from 1960.

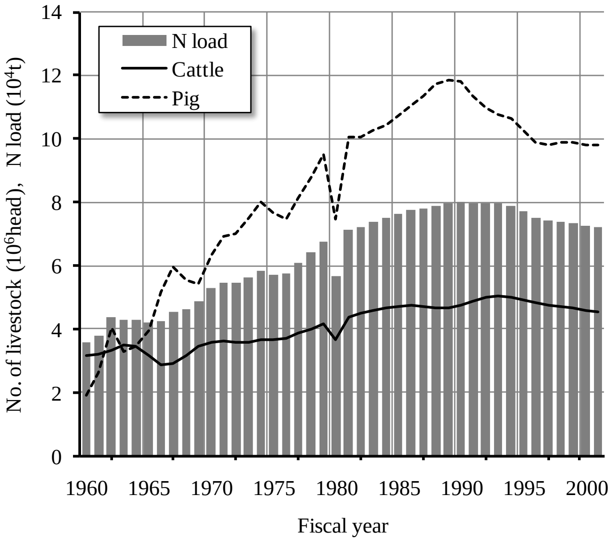

Fig. 3 Changes over time in the numbers of livestock raised and the N load produced from them.

Converting livestock waste into manure and spreading it on cultivated land presents no problems as long as the amount produced does not exceed the demand. As shown in **Figs. 2** and **3**, 70,000 t of N load is produced a year and approximately five million ha of land are cultivated. On a Japan-wide average, 16 kg ha^{-1} of manure could be applied to cultivated land and the supply would still remain at a sufficient level. However, livestock farming is regionally intensive, so an excess of livestock waste could cause regional environmental problems.

Japanese government policy for environmentally-sound agriculture

As mentioned above, although the demand for fertiliser per unit of cultivated land has levelled off in these twenty years, the level is higher than that before 1970, when water pollution came to be a crucial problem in Japan. The pollutant loads produced from livestock farming are also as high as ever. To reduce pollutant loads from agriculture is necessary to conserve the water environment. In addition to this, in recent years, crop consumers and citizen have tended to request organically grown crops, which have less fertiliser and pesticides applied than the ordinary.

Table 2 shows the outline of the policy for environmentally-sound agriculture promoted by MAFF of Japan, which has been implemented since 1992. The specific purpose of the policy is to reduce the amount of fertiliser and pesticide used on cultivated land, and to complete sufficient treatment of livestock waste.

In 1999, MAFF of Japan enacted three laws concerning promoting sustainable agricultural production practices, and appropriate management and utilisation of livestock waste to improve the "natural cyclical function of agriculture," constructing collaboration between livestock farmers and land cultivating farmers. These laws have significant meaning in that the national government systematises action implemented and planned to contribute to sustainable agriculture.

ROLES OF CULTIVATED LAND ON NITROGEN FLOW

As mentioned above, agriculture and rural areas play multifunctional roles. One function,

Table 2 Outline of the policy for environmentally-sound agriculture.

Structure for organising promotion	· Organising in every local government · Drawing up the basic concept and charter for eco-friendly agriculture
Development of technology	· Developing technology for soil consolidation, reducing fertiliser and pesticides · Practical proving of the technologies · Finding and estimating traditional technologies · Developing eco-friendly materials, such as coated fertiliser, bio-pesticide, and agricultural machinery
Providing newly developed technology and information	· Making guidelines for eco-friendly agriculture · Reconsidering the standard for fertilisation · Organising a soil diagnoses system · Substantiating prediction of agricultural damage
Support for introducing new technology and facilities	· Governmental certification of farmer's plan for highly productive agriculture · Financial support for eco-friendly agriculture
Promotion of recycling organic waste	· Construction of recycling system and facilities for organic resources · Promotion of recycling of agricultural materials
Preparing social conditions	· Education of eco-friendly agriculture to consumers · Labelling of eco-friendly agriculture

for example, is water purification. The major proportion of land in rural areas is occupied by paddy fields, upland fields, irrigation and drainage facilities, and wetlands. Every land use has different effects on the water environment. Although many previous studies have tried to establish and quantify the roles of cultivated land in water purification and pollution, few have successfully quantified every process contributing to water quality, since chemical and biological reactions in water are complicated and vary with natural and social conditions.

Nitrogen removal in paddy fields and wetlands

Paddy fields remove N when the irrigation water is highly contaminated with N. Shiratani *et al.* (2008) reported the relationship between N removal in a paddy field in which N fertiliser was applied at a standard rate of 70 to 100 kg ha^{-1} and the N concentration in the irrigation water. This is shown in **Fig. 4**. The regression equation is as follows:

$$R = 0.011 \cdot C_{irrigation} - 0.016, \quad [1]$$

where R = amount of N removed per cultivation day (g m^{-2} d^{-1}) and $C_{irrigation}$ = N concentration of irrigation water (mg L^{-1}). The amount of N removed per unit cultivation day was proportional to the N concentration in the irrigation water, with a proportional constant of 0.011 m d^{-1}, in paddy fields in which the N concentration of irrigation water was ≥1.45 mg L^{-1}. As only 3% of the data plotted in **Fig. 4** for which the N concentration of irrigation water was more than 2.0 mg L^{-1} had negative values of R, it seems reasonable to suppose that paddy fields remove N when the N concentration of irrigation water is higher than 2.0 mg L^{-1}. The case where paddy fields become N pollution sources is interpreted that the N loading rate, including elution from sediment and fertilisation, could exceed the N removal rate owing to denitrification, algal uptake, plant uptake, and sedimentation when the N concentration of the irrigation water is lower than 2.0 mg L^{-1}.

Nitrogen pollution by upland fields

The amount of N discharged from upland fields and orchards depends on the amount of fertiliser applied. Approximately 30% of N applied in fertiliser could effuse out of the field as shown in **Fig. 5** (Shiratani *et al*., 2008). This basically means that N outflow from upland fields could likely be controlled by reducing fertilization.

While the average N concentration in the drainage water from upland fields and orchards was estimated at 5.5 mg L^{-1} (Shiratani *et al*., 2005), ground or spring water in the area where vegetable cropping, tea cropping, and livestock farming are highly concentrated often has a nitrate/nitrite N concentration of more than 10 mg L^{-1} (water quality standard for human health, enacted by the Ministry of the Environment).

Economic valuation of agricultural impact on water environment

The N removal function of cultivated paddy fields and fallow paddy fields was valued at approximately 0.3 JPY m^{-2} d^{-1} and 0.6 JPY m^{-2} d^{-1}, respectively, when replaced by the sum of maintenance and depreciation costs of water quality improvement facilities (RCM: Replacement Cost Method). On the other hand, the upland field cultivation was valued at negative economic value of approximately 0.08 JPY m^{-2} d^{-1} by the RCM. Also note, however, that paddy fields function effectively in N removal only when the irrigation water is strongly contaminated with N. Consequently, 85% of the area used for paddy fields does not function in N removal. As a result, cultivated lands, comprising paddy fields and upland fields Japan-wide, can be externally economically valuated at approximately minus 744 billion JPY annually. (Shiratani *et al*., 2008)

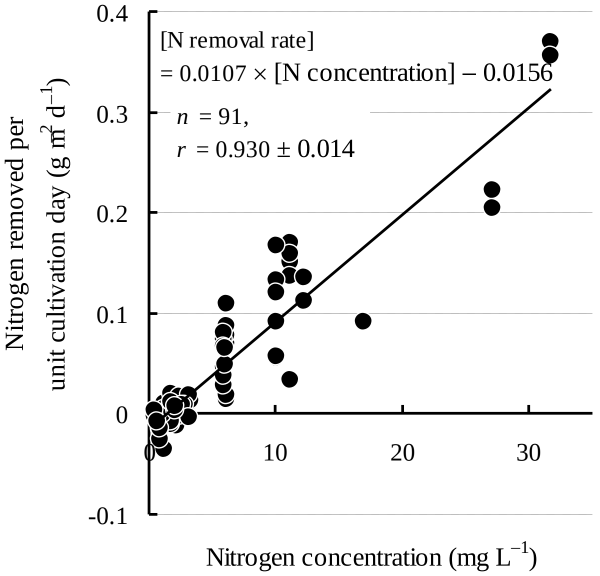

Fig. 4 Relationship of nitrogen removal in paddy fields to nitrogen concentration of irrigation water.

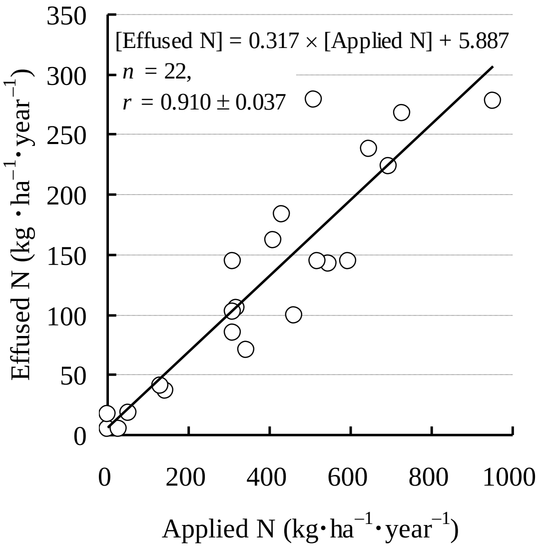

Fig. 5 Relationship of nitrogen effused from upland fields to applied nitrogen fertiliser.

To conserve water quality in a watershed, a sound nutrient and water cycle must be developed.

PRACTICAL USE OF NITROGEN REMOVAL IN PADDY FIELDS

Recycle of gray water

A significant quantity of pollutant load effuses out of domestic drainage. Nowadays, most

Table 3 Scenarios analysed.

Scenario 1	Irrigating paddy fields with sewage-treated –waters (recycle irrigation), and reducing water withdrawn from river corresponding to the recycle irrigation, throughout the year.
Scenario 2	Recycle irrigation, but not reducing water withdrawn from the river, throughout the year.
Scenario 3	Recycle irrigation, and reducing water withdrawn from the river, only during the cropping period.
Scenario 4	Recycle irrigation, but not reducing water withdrawn from the river, only during the cropping period (April – September).
Scenario 5	Recycle irrigation, and reducing water withdrawn from the river, only during the non-cropping period.
Scenario 6	Recycle irrigation, but not reducing water withdrawn from the river, only during the non-cropping period (October – March).

domestic water is mains-supplied and drains to sewage works, and sewage works covered 82.6 million people (65.2% of Japan's population in 2002) in Japan (MLIT of Japan, 2004). Assuming the unit of domestic effluent to be 0.3 m^3 d^{-1} per capita, the total amount of effluent is nine thousand million m^3 annually, which is approximately 15% of the amount of irrigation water for paddy fields in Japan, 59.3 thousand million m^3 (Itami and Sueyoshi, 1998). Such a large quantity of effluent water is discharged with no reuse.

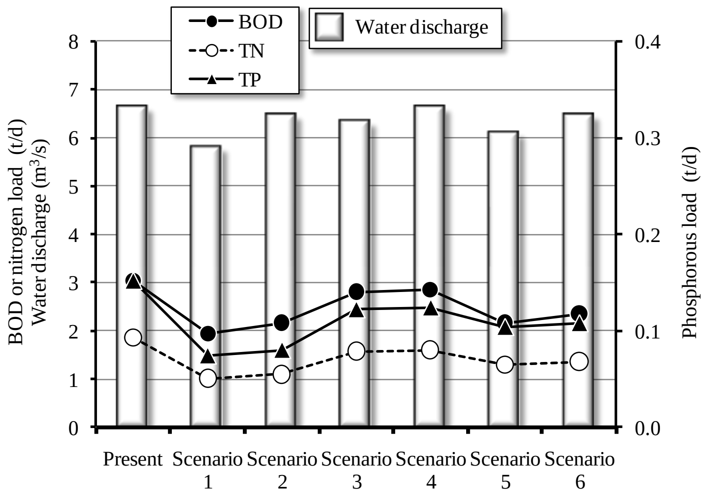

Fig. 6 Discharge of water and pollutant load from the watershed into the lake.

To make better use of limited water, it might be necessary to build small-scale sewage plants that make use of the ability of paddy fields to purify water. A mathematical model which analyse the transport of water and pollutants in a watershed was applied to the watershed of Abragafuchi Lake, Japan (Total area = 65.6 km^2, of this total, 63.2% are paddy fields. Population = 90,994, of them, 38.5% are sewage treated.), where serious water pollution has occurred over three decades, and scenarios of recycling sewage treated-water into agriculture (**Table 3**) to reduce pollutant load discharged into the lake were analysed (Shiratani *et al*., 2010). The results show that irrigating paddy fields with the sewage-treated water could contribute to conserving water and reducing pollutant load, with reduction rate in BOD, nitrogen, and phosphorus ranging from 6%–36%, 16%–46%, and 18%–51%, respectively (**Fig. 6**). Particularly, the results indicate that, irrigating paddy fields with the treated water during non-cropping periods and the accompanying reduction in withdrawn water from the river are more effective in reducing pollutant loads discharged into the lake.

Although problems such as heavy metal contamination need to be solved, small-scale sewage plants have potential for water recycling because of ease of control. Kunimatsu *et al*. (1998) reported that the concentrations of cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb), and

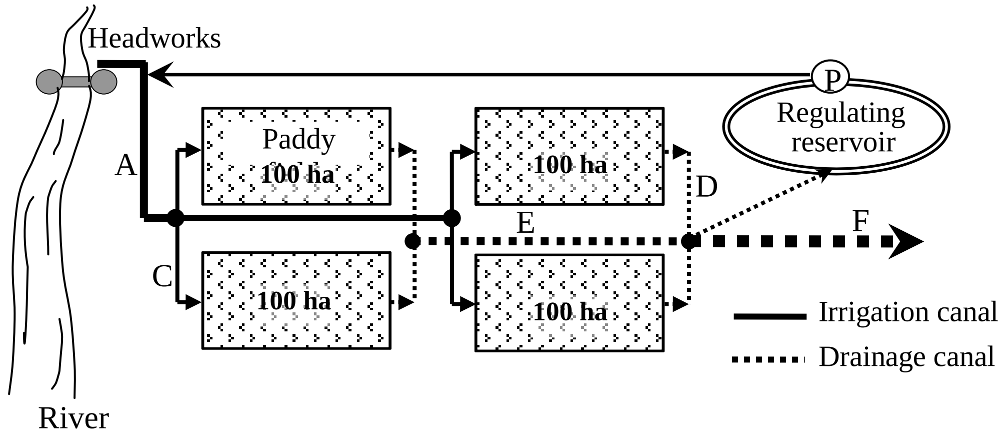

Fig. 7 Model paddy field irrigation system used in analysis.

arsenicum (As) in the harvested rice grains produced in a paddy field irrigated with effluent from a rural sewage treatment plant did not increase.

Reuse of paddy field drainage

As described above, paddy fields rarely contribute to purify water when the N concentration of the irrigation water is low, less than 2.0 mg L^{-1}. In that case, recycling of the paddy field drainage within the paddy field area could be effective in reducing the load from the area. Shiratani *et al.* (2004) developed a mathematical model to simulate water and nutrient flow in four 100-ha paddy field blocks equipped with irrigation canals, drainage canals and a regulating reservoir (1.5 m depth) with a pump (**Fig. 7**), and estimated the efficiency of recycling of paddy field drainage at reducing N load discharge.

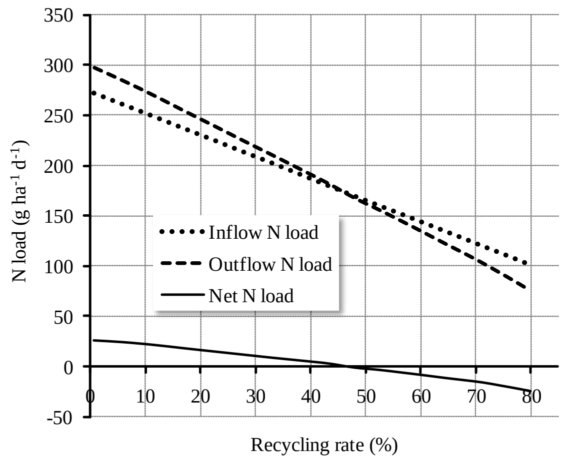

Fig. 8 Nitrogen load of inflow and out flow and net nitrogen load discharge in the model in Fig. 7.

The net N load discharge, defined as the balance between inflow and outflow loads, was approximately 25 g ha^{-1} d^{-1} without recycling, and decreased with an increase of recycling rate (ratio of water introduced into the regulating reservoir to water drained from the paddy fields). At a 48% recycling rate, the net N load discharge was zero. This means that the paddy field area could purify N in water at a recycling rate of 48% or more.

On the other hand, the N concentration of irrigation water will increase and the water environment should therefore deteriorate as the recycling rate increases. Increased nutrient concentrations in irrigation water in agricultural areas where water recycling systems are constructed have been found in field examinations and model analyses (*e.g.,* Kaneki, 1991; Kudo *et al*., 1995; Feng *et al.*, 2004; Hitomi *et al.*, 2006).

Extending the water retention time in all agricultural areas and reusing water could enhance the capacity of agriculture to remove N.

Recycle of upland field drainage

Paddy fields and wetlands have N removal functions. On the other hand, upland fields release N. Nakasone *et al*. (1996) examined the N removal functions of paddy fields in the N flow on agricultural catchments, and found that paddy fields located at the hill-bottom effectively removed N leached from upland fields located on the hill. To construct the N flow from upland fields to paddy fields should be effective to reduce N load outflow from the agricultural catchment.

When the removal of N by paddy fields balances N pollution from upland fields, the state can be expressed by the following equation:

$$A_u R_u = A_p R_p, \qquad [2]$$

where A_u = area of upland fields (m^2), A_p = area of paddy fields (m^2), R_u = N loading rate of upland fields (g m^{-2} d^{-1}), and R_p = N removal per unit cultivation day of paddy fields (g m^{-2} d^{-1}).

The N loading rate of upland fields is expressed as $R_u = QC_{eff}$, where Q = water drainage rate (m d^{-1}) and C_{eff} = N concentration of drainage water (mg L^{-1}). The N removal rate of paddy fields is expressed as $R_p = f\,C_{irrigation}$ (approximated from eq. [1]). When $C_{eff} = C_{in}$:

$$A_u/A_p = f/Q. \qquad [3]$$

If $f = 0.01$ m d^{-1} and $Q = 2.74 \times 10^{-3}$ m d^{-1}, where the water drainage rate is assumed to be the balance of daily average rainfall and evapotranspiration, then:

$$A_u/A_p = 3.65. \qquad [4]$$

That is, a unit area of paddy field could purify N-polluted drainage from 3.65 times that area of upland fields (Shiratani *et al.*, 2005).

However, in reality, there are problems to be solved before we can apply this idea at actual sites. Although large upland field drainage occurs over a couple of days after rainfall, paddy fields never require irrigation water on those days, so we cannot directly recycle the field drainage for irrigation of paddy fields. To solve this, an irrigation, drainage, and storage system is required. The system should have an adequate scale of regulating reservoirs to regulate the timing between upland field drainage and water requirement in paddy fields while consistent 100% reuse is not achievable.

RELATED SUBJECTS

Water has multiple uses, including irrigation, conservation of rural amenity, bio-conservation, and household needs, thus, conservation of the water environment is essential for sustainable development of rural areas. As described above, to reduce discharge loads from agricultural areas, in one way, may result in the accumulation of organic matters and nutrients, and this may cause the deterioration of water environment in agricultural area itself. Suitable water environments for respective water uses need to be clarified, and innovative water-use systems need to be developed to achieve a good rural environment.

The water quality standard for public water area in Japan was revised in 2003, and a heavy metal, Zn, was added as the standard for conservation of aquatic lives. In the course of the revision, while Cd had been listed among chemicals which could harm in living beings, it was decided not to take up Cd in the last result because the quantitative analysis of Cd at the level to be set as the standard was impossible by the atomic absorption determination which is widely used at that time (Sudo, 2004). Investigation of heavy metal concentration in irrigation water by higher-accuracy method is necessary for near future. At the same time, to cope with the Codex Alimentarius Commission in which the standard for heavy mental content in foods was revised can be an important issue for the field of irrigation and drainage in view of the fact that both the nation and the world market request safe foods to agriculture.

In addition, the role of the national and local governments in environment measurements needs to be discussed since the “rural resources” including farmland and water management facilities have the bilateral character, which is private and public goods (Yamashita, 2007). The national government should involve with equitable sharing the burden to sufficiently supply the rural resource among local governments with different industrial structure, and with the improvement of water management facility within its backbone which gives less multifuctionality but essential function. To compensate farmers for reductions in agricultural productivity due to the environmentally-sound agriculture should also be considered an important factor in achieving the sustainable development of agriculture.

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