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Nitrogen Concentration in Irrigation Water and Its Effect on Rice Growth and Soil Properties

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Abstract
By analyzing the actual condition of water quality in an irrigation ditch in Saitama Prefecture, the effect of water quality on paddy rice characteristics and soil environment was demonstrated. It was recognized that the function of paddy fields controlled paddy rice characteristics and also became an important factor for the preservation of water quality. Especially, based on experiment and field tests to apply sewage with secondary processing for irrigation, it was confirmed that the actual condition of agricultural utilization of water could be determined by quality checks. Additionally, after the influence of sewage irrigation on the soil properties and growth of crops was investigated, the maximum permissible concentration of nitrogen in irrigation water was determined and criteria for cultivation were developed.

Discipline: Agricultural environment
Additional key words: permissible concentration, water resource, sewage with secondary processing

Introduction

When the water system is associated with a high level of utilization in large cities, it is important to secure a stable supply of water to meet future demand. On the other hand, pollution of irrigation water is a major problem linked with water utilization due to urban sewage[4,6]. In such areas, there may be a serious water shortage and water pollution may damage paddy rice[7,9,10].

In this paper, the following aspects were dealt with: 1) the actual condition of irrigation water and the factors responsible for changes observed in recent years were clarified by conducting surveys on water quality during the period 1942 – 1988, 2) brown rice yield in paddy fields where fertilizer had not been applied for 85 years was analyzed to determine the influence of nitrogen concentration on the growth of paddy rice, and 3) the influence of sewage irrigation on the characteristics of paddy rice and purifying function of paddy fields were studied.

Additionally, the changes in the conditions of nitrogen in the water of irrigation ditches in paddy fields located near large cities and the utilization of water resources[2] were reviewed.

Changes of water quality in irrigation ditches

The nitrogen concentration of the water in a river which was less polluted in comparison with others was 0.36 mg L^{-1} in 1942, 0.58 mg L^{-1} in 1952, 0.70 mg L^{-1} in 1964, 1.57 mg L^{-1} in 1974, 2.50 mg L^{-1} in 1977. Although the concentration had increased as shown in Fig. 1, it has remained at the same level of about 2.0 mg L^{-1} in recent years.

The average values of the components of the water quality in the river used for irrigation (10 rivers, 65 irrigation ditches, 1,060 samples) in recent years

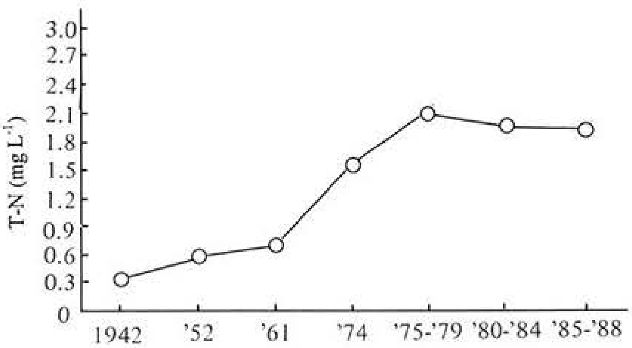


Fig. 1. Changes in nitrogen concentration in water in irrigation ditch
(less polluted irrigation ditch in Saitama Prefecture)

were as follows: pH 7.4, EC 0.272 dS m^{-1}, DO 6.3 mg L^{-1}, T-N 2.7 mg L^{-1}, NO_3-N 1.4 mg L^{-1}, NH_4-N 0.3 mg L^{-1}. The quality of irrigation water experienced major changes associated with the utilization of land along the drainage basin. In paddy fields in small settlements, irrigation water tended to be polluted by the drainage from the settlements. The main pollution causes in the rivers near cities or inland areas included sewerage system, soil disposal facilities and simplified disposal of waste water. The loading amount of T-N and COD was 95% in the waste water and the pollution rate was 90% for T-N and 52% for COD (Table 1). Hiki area, where the supply of irrigation water was inadequate, introduced urban drainage (T-N 12 mg L^{-1}) as the main source of irrigation (Table 2).

The average values of the components of the quality of irrigation water in the area, which affected the growth of paddy rice were as follows: EC 0.376 dS m^{-1}, SS 12 mg L^{-1}, T-N 6.0 mg L^{-1}. When the rate of NH_4-N exceeded 40% in T-N, the lodging index level increased.

Table 1. Loading amount of T-N, COD in a large city area

		T-N	COD
Generation loading	(kg d^{-1})	210	660
Domestic water	(%)	96	95
Livestock waste	(%)	1	2
Others	(%)	2	3
Survey loading	(kg d^{-1})	190	340
Pollution rate	(%)	90	52

Sewage irrigation affected the transformation of soil organic nitrogen. The concentration of non-extractable acid soluble nitrogen increased when the T-N level exceeded 7 mg L^{-1} (Table 3).

Rice yield in paddy fields without fertilizer application during a period of 85 years

Since 1904, Saitama Agricultural Experiment Station has carried out an experiment in lime application to paddy fields, which is a unique long-term experiment with fixed design in Japan.

At the onset of the experiment, the yield of rice which was 2.7×10^3 kg ha^{-1}, afterwards decreased to 1.1×10^3 kg ha^{-1} in 1934. For 20 years until 1954 the yield remained almost at the same level of 1.5×10^3 kg ha^{-1}. However after 1955 the yield increased, reaching a value of 3.8×10^3 kg ha^{-1} in 1973. During the period from 1975 until 1989, the yield remained at the level 2.3×10^3 kg ha^{-1} (Fig 2).

The total nitrogen concentration of irrigation water ranged from 0.28 to 0.36 mg L^{-1} in 1935; 0.54 to 0.58 mg L^{-1} in 1945; 0.58 to 0.72 mg L^{-1} in 1955; 1.0 to 1.28 mg L^{-1} in 1965; 1.80 to 2.57 mg L^{-1} in 1975; 2.15 to 3.10 mg L^{-1} in 1985; the average yield being 1.57, 1.59, 2.16, 2.74, 2.89, and 2.57×10^3 kg ha^{-1}, respectively in these years.

The total nitrogen content in the topsoil was 2.0 g kg^{-1} in 1928, 1.4 g kg^{-1} in 1952, and 1.3 g kg^{-1}

Table 2. Changes of water quality in irrigation ditch in a large city area

(dS m^{-1}, mg L^{-1})

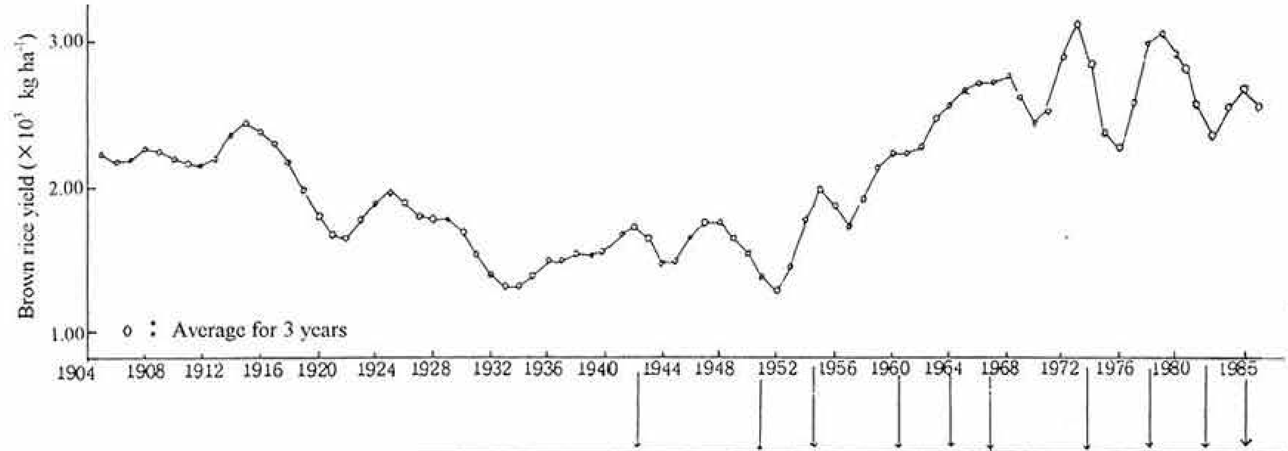
River basin		pH	EC	DO	COD	T-N	NH_4-N	NO_3-N	T-P
Upland field	(upper part)	6.3	0.234	8.9	6.4	7.91	0.99	6.25	0.23
Town	(middle part)	7.1	0.300	6.3	11.5	5.98	2.11	2.19	0.98
Paddy field	(lower part)	7.1	0.382	6.2	11.3	11.89	6.46	3.70	1.31

Table 3. Nitrogen concentration of irrigation water and composition of organic nitrogen in paddy soil

N concentration in irrigation water (mg L^{-1})				Org-N concentration in paddy soil[a)] (g kg^{-1})				Lodging index level[b)]
T-N	NH_4-N	NO_3-N	Org-N	T-N	Hyd-N	Sol-N	Insol-N	
10.9	5.1	3.1	2.7	3.15	2.46	0.98	1.48	5
8.5	3.9	2.7	1.9	3.00	2.36	0.83	1.53	4
7.3	3.0	2.6	1.7	2.97	2.17	0.67	1.50	4
5.6	1.7	2.3	1.6	2.43	2.06	0.77	1.29	2
4.8	1.4	2.0	1.4	2.48	1.78	0.68	1.10	2

a): Hyd-N; Acid hydrolysable nitrogen, Sol-N; Acid soluble nitrogen, Insol-N; Acid insoluble nitrogen. Hyd-N consists of Sol-N and Insol-N.

b): Lodging index level: 0 (no lodging) - 5 (lodging with breaking of strength lower internodes).



T-N	($mg\ L^{-1}$)	0.28	0.54	0.72			1.00	1.23	1.80	2.57	3.00
NH_4-N	($mg\ L^{-1}$)	0.02	0.10	0.04	0.01	0.45	0.14	0.33	0.57	0.10	0.08
NO_3-N	($mg\ L^{-1}$)	0.21	0.44	0.68	0.46		0.51			1.40	1.99
P	($mg\ L^{-1}$)	0.00		0.01	0.01			0.10	0.16	0.10	0.10
EC	($dS\ m^{-1}$)				0.165			0.250	0.248	0.209	0.195

Fig. 2. Yield of brown rice in paddy field without fertilizer application during 85 years, and irrigation water quality

in 1957, suggesting that the content of nitrogen in the soil had been reduced by 30 to 40% during a period of about 30 years with a concomitant reduction of yield amounting of 10 to 20%. There was no significant change in the total-nitrogen content in the topsoil for 27 years until 1983. However, the production of ammonium nitrogen determined by the incubation method was 68 mg kg^{-1} in 1984 against 48 mg kg^{-1} in 1957, and the air-drying effect on ammonification increased from 15 mg kg^{-1} up to 40 mg kg^{-1}.

On the other hand, the carbon content in the topsoil, which was 7.5 g kg^{-1} in 1951, increased to 11.5 g kg^{-1} in 1984, presumably due to the increase in the biomass production by aquatic plants in the paddy fields due to eutrophication of irrigation water. Thereafter, organic matter of roots and stubbles accumulated under the low C/N ratio of the topsoil.

The increase of yield between 1956 and 1975 was ascribed to the increase in the nitrogen load from irrigation water. It is also possible that the carbon content and air-drying effect on ammonification in soil were enhanced due to the presence of aquatic plants such as algae and lemna whose nutrition sources are NO_3-N and NH_4-N in the irrigation water.

The sluggish increase in rice yield for the last 15 years may be due to the fact that the content of other essential elements except for nitrogen did not increase and due to the changes in the meteorological conditions in recent years.

Maximum permissible concentration of nitrogen in water for paddy field irrigation

In this chapter, the effect of the use of sewage for irrigation on the characteristics of paddy rice with Nipponbare as a test sample was studied[3]. The conditions of water quality associated with sewage with secondary processing supplied for irrigation use were analyzed and the maximum permissible concentration of elements in irrigation water was determined in relation to: 1) direct utilization of sewage water with secondary processing in areas with serious water shortage, and 2) indirect utilization when water resources are available and the development of criteria for cultivation.

The quality of sewage water with secondary processing showed conspicuous hourly changes. There was a close correlation between the content of SS (suspended solids) and Org-N (organic nitrogen) in the sewage water. In processed sewage water SS contained 50% of total-Zn. For the use of processed sewage water for irrigation, it was important to prevent soil contamination with efflux of SS[8].

The concentration of nitrogen in the irrigation water, yield and yield components could be represented by a curve similar to the law of diminishing returns. In conventional fertilization, optimum yield was achieved at a nitrogen concentration of about

5 mg L^{-1}. However, this is the limit in the present system of agricultural technology. In this case, the impact on plants and soil should be minimized.

The level of total-nitrogen concentration for the direct utilization of sewage water with secondary processing was fixed at values ranging for 3.0 to 4.0 mg L^{-1} based on the lodging index, yield and yield components, with a maximum concentration of 5.0 mg L^{-1}.

Criteria adopted in case of direct utilization of processed sewage water, assuming that the growth limit of paddy rice corresponds to the 3rd grade of lodging index are as follows:

Number of panicles : 400 pcs m^{-2},
Number of spikelets : 32,000 grains m^{-2},
Maximum number of stems:
540 pcs m^{-2} (at the panicle formation stage),
Amount of nitrogen absorption:
9.6 g m^{-2} (at the same stage),
Nitrogen content : 2.5 to 2.7% for stems,
Nitrogen content : 2.7 to 2.8% for lamina.

For stable growth the nitrogen content during the ripening stage was fixed at 1.6% for stems and 2.9 to 3.1% for lamina.

On the other hand, the maximum concentrations for indirect utilization of sewage water with secondary processing based on lysimeter determinations (Fig. 3, Table 4) were as follows: T-N; 2.4 to 3.3 mg L^{-1}, Cu; 0.01 to 0.02 mg L^{-1}, Zn; 0.04 to 0.05 mg L^{-1}.

Also there was a relationship between the nitrogen concentration of irrigation water and growth of paddy rice as well as effect on paddy soil properties (Table 5).

When the NH_4-N concentration in irrigation water was 3.0 mg L^{-1}, 8 to 23% were absorbed in paddy rice. The maximum level of absorption corresponding to 63% of NH_4-N occurred from the panicle formation stage to the meiosis stage. When the level of NO_3-N was high (15.0 mg L^{-1}), 36.4% was absorbed by paddy rice. Maximum absorption ranging from 46 to 56% occurred from the meiosis stage to the milky stage.

The water quality remarkably influenced not only the growth of paddy rice but also the environment of the culture medium and the root systems. A large amount of roots grew at the onset of cultivation when the NH_4-N concentration of water was 15.0 mg L^{-1}. The roots became gradually darker after

N : 12.8 mg L^{-1} (average concentration in irrigation water)
| 510.7 × 10^5 L ha^{-1} / 2 years (irrigation)
N : 678 kg ha^{-1} / 2 years (influx amount from water)
|
N : + 520 kg ha^{-1} (balance)
|
N : 158 kg ha^{-1} (permissible amount*)
|
N : 3.1 mg L^{-1} (permissible concentration)

Fig. 3. Estimation of permissible concentration of nitrogen
*Reference to comment in Table 4.

Table 4. Permissible concentration of elements in sewage water with secondary processing for irrigation

		N	Cu	Zn
Element contents in irrigation water (mg L^{-1})		7.3-14.9	0.02	0.15
Influx amount (input) (A)	(10^2 kg ha^{-1} in 2 years)	3.6-8.5	0.01	0.08-0.10
Efflux amount (output) (B)	(10^2 kg ha^{-1} in 2 years)	1.1-2.2	0.01	0.03
Balance (A-B)	(10^2 kg ha^{-1} in 2 years)	2.5-6.3	0-0.01	0.05-0.07
Permissible amount	(10^2 kg ha^{-1} in 2 years)	1.1-2.2	0.01	0.03
Permissible concentration*	(mg L^{-1})	2.4-3.3	0.01-0.02	0.04-0.05

1. These data were obtained in lysimeter experiments under conventional fertilizer application.
2. Input (irrigation water + rain), output (plant + eluviation).
3. Water requirement in depth: 22.5-32.7 mm d^{-1}.
4. The nitrogen permissible amount excludes the denitrification amount, to minimize the impact on the growth of crops.
5. The permissible concentration was determined to convert the large quantity of urban sewage (indirect utilization of sewage water with secondary processing into a new water reservoir).

* Apparently no accumulation into soil from irrigation water (influx amount − balance).

Table 5. Relationship between nitrogen concentration of irrigation water and growth of paddy rice and nitrogen content of topsoil

Level of T-N (mg L^{-1})	Determined T-N (mg L^{-1})	Influence of nitrogen in irrigation water on paddy rice growth and nitrogen content of topsoil
1.0	0.6<	Increase of yield in the absence of fertilizer application
2.0	2.7	Average concentration in water in irrigation ditches (Saitama Prefecture) No significant change in nitrogen content of topsoil
3.0	3.3	Maximum permissible concentration (indirect utilization of processed sewage) Safety level: <3.0-4.0 mg L^{-1}
4.0	4.0-5.0	Effect of nitrogen was observed in the topsoil. Optimum yield was achieved at the level.
5.0	5.0	Limit of current cultivation techniques (found by direct application of processed sewage) Small amount of accumulation of organic nitrogen was found in top-soil when large amount of irrigation water was used.
6.0	5.6-6.0	Extensive damage of paddy rice
	7.0<	Increase of organic nitrogen concentration in topsoil

Soil: Fine-textured Gray Lowland soil. Variety: Nipponbare.

the heading period and the activity of the root system decreased. When the NO_3-N concentration of irrigation water was 15.0 mg L^{-1}, the level of Eh in soil increased and the root system became active. The condition of the root system and of the environment of the culture medium affected the growth of tillers as well as the nutrient status and distribution.

Conclusion

This report dealt with the effect of the use of sewage water for irrigation on the soil properties and growth of crops and the maximum permissible level of nitrogen concentration was determined. These results can be applied to inland areas which face serious water shortage and when paddy rice sustains considerable damage. A method to transfer a large quantity of urban sewage into a new water reservoir for these areas and to achieve stable rice cropping was developed.

The use of sewage for irrigation is a method aimed at a high level of water utilization, whereby crop production and water quality preservation are combined to improve the water quality while utilizing effectively the self-purifying function of paddy fields[5]. The impact on the growth of crops and systems of agricultural technology should be considered carefully and environmental chemical studies should be carried out.

For example, there was a mutual relation between the ecosystems of the paddy fields and nitrogen concentration in the irrigation water. The interaction of the nitrogen purifying function involved absorption and volatilization at a high pH by aquatic plants and reduction by algae[1] in addition to absorption by paddy rice, fixation by soil and denitrification, which were promoted when the nitrogen concentration in the irrigation water ranged from 3.0 to 5.0 mg L^{-1}. This function was the most important for the use of sewage water with secondary processing for irrigation.

Therefore, these aquatic plants must be considered as organic materials which have a high density function of self-purification through the function of paddy fields and their properties should be investigated for effective use.

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