EFFECT OF INTENSIVE FERTILIZER USE ON GROUNDWATER QUALITY

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ABSTRACT

Although fertilizer nitrogen makes a great contribution to an increase in crop yields, excess fertilizer nitrogen is polluting groundwater with nitrate in countries which use large amounts of fertilizer. In the case of Japan, groundwater pollution is serious in areas producing vegetables, fruit, tea and livestock.

The mean amount of nitrogen which was not absorbed by different kinds of crop was estimated, using statistical data on fertilizer application rates. Municipalities which have high levels of non-absorbed nitrogen due to excessive use of nitrogen fertilizer had high concentrations of nitrate in their groundwater. A municipality which made an effort to reduce nitrogen fertilizer succeeded in improving groundwater quality. This Bulletin stresses the importance of reducing nitrogen applications in countries with heavy fertilizer use, while maintaining yield levels.

RECENT TRENDS IN NITROGEN USE

It is well known that chemical fertilizers are necessary to increase food production. Most countries increased their consumption of fertilizer nitrogen (N) after World War II, and in this way were able to increase their food production (Fig. 1).

Fig. 2 shows that the mean yield of all cereals has increased in proportion to the rise in fertilizer N consumption in developing countries up to the present day.

The same trend was seen in the EU up until 1988. However, it is noteworthy that the yield of total cereal in the EU lost this positive relationship with fertilizer N use after 1989. Many EU countries applied much more fertilizer N than was needed by plants. This caused serious water pollution when nitrate leached from agricultural land. These countries have recently taken measures to reduce fertilizer consumption. However, the cutback in fertilizer use did not lead to any reduction in cereal yields.

RECENT TRENDS IN NITROGEN USE IN JAPAN

A trend similar to that shown in Fig. 2 was also seen in rice production in Japan. After World War II, the Japanese government adopted a generous price support policy to stimulate rice production and overcome food shortages. Farmers grew high-yielding rice varieties with heavy applications of fertilizers in order to get the maximum yield, because the government purchased all the rice they produced at a good price. The mean amount of fertilizer N applied to rice increased from 69 kg/ha in 1952 to 108 kg/ha in 1986.

During this period, the yield of brown rice increased significantly in step with the amount of fertilizer N used (Fig. 3). In general, the appropriate level of fertilizer N for high-yielding rice varieties is 80-110 kg/ha. (It varies according to the variety and local conditions). However, many farmers applied too much.

Excessive fertilizer use caused the

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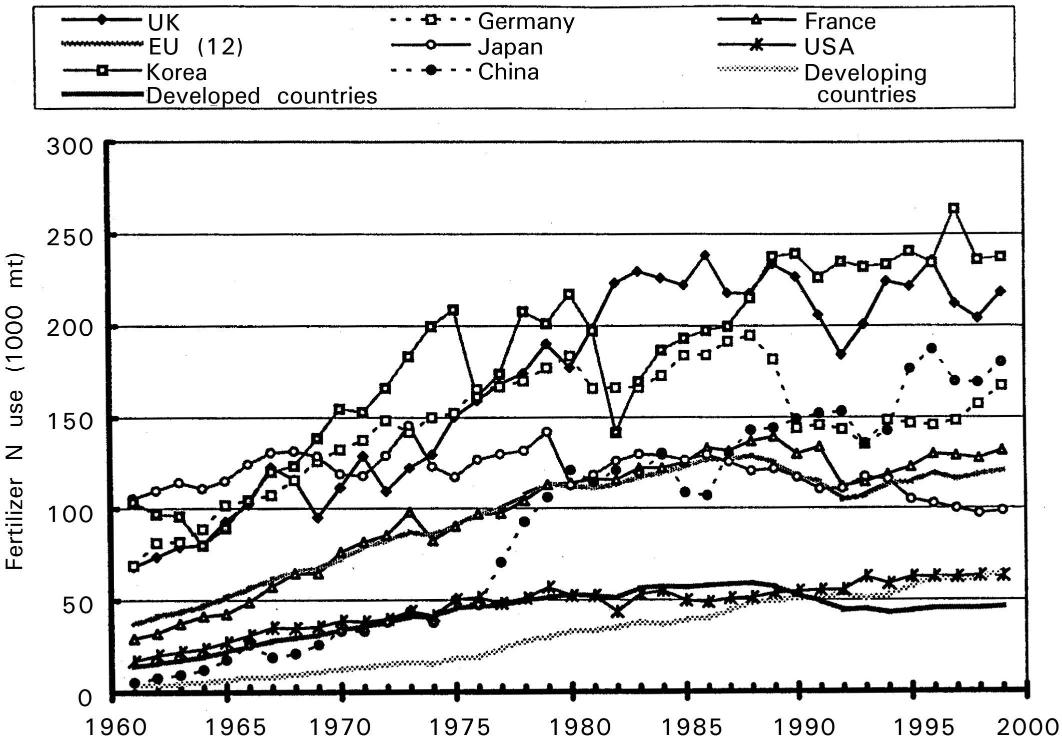

Fig. 1. Changes in fertilizer N consumption per unit area of annual and perennial crops in developing and developed countries

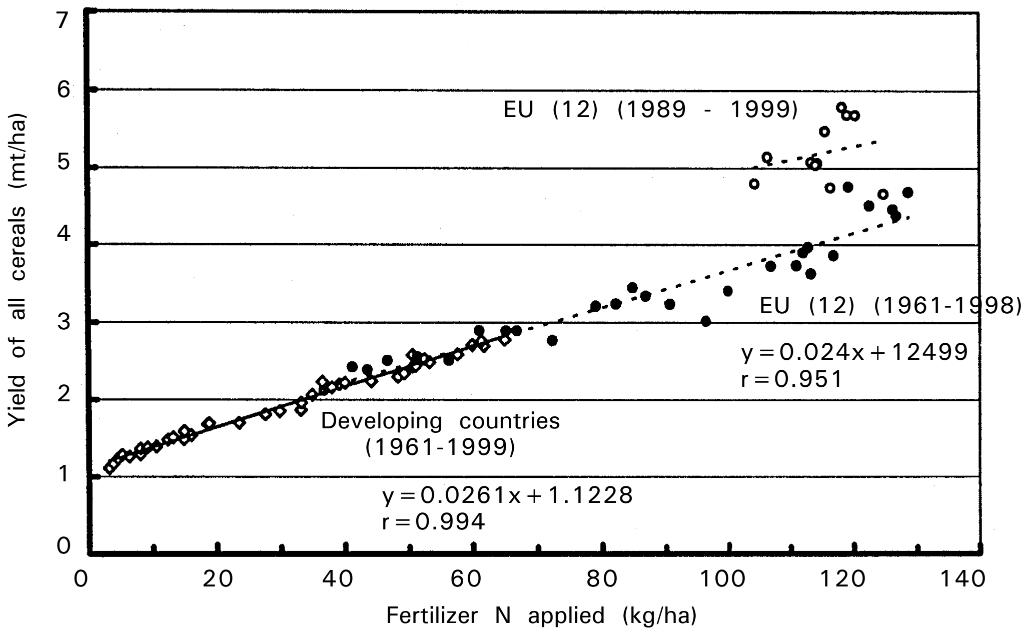

Fig. 2. Relationship between fertilizer N consumption per unit area of arable and perennial crops, and yield of total cereals, in developing countries and EU

Source: FAOSTAT

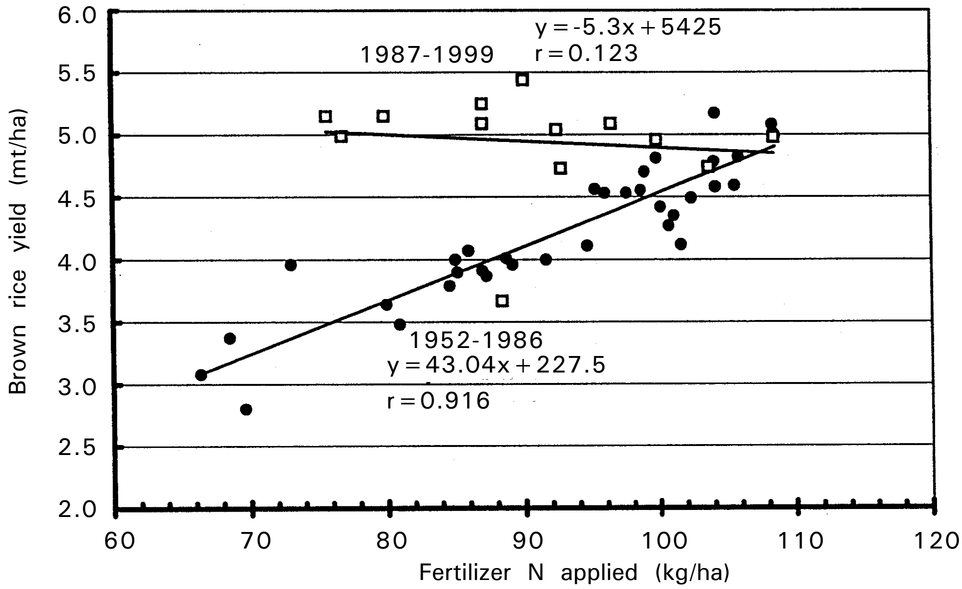

Fig. 3. Relationship between the amount of fertilizer N applied and yields of brown rice in Japan
Source: Nishio 2002

eutrophication of surface water, when nitrate and phosphate escaped from paddy fields into rivers and lakes via drainage canals. This was particularly common when ponded water was released after puddling, even though paddy soil has a high capacity to purify the water percolating through soil layers, thus protecting groundwater quality.

The price support policy was very effective in helping to increase rice yields, from 3.4 mt/ha in 1952 to 5.2 mt/ha in 1986. However as living standards rose, the consumption of rice decreased. A surplus in rice production became apparent in the late 1960s. From 1970, the Japanese government limited the area planted in rice. After 1987, the price support for rice was reduced, and from 1995 was paid only under special circumstances. All this meant a fall in rice prices. The lower prices for rice dramatically lowered the amount of fertilizer N applied to rice, from 108 kg/ha in 1987 to 76 kg/ha in 1999. Nevertheless, there was no reduction in the yield of brown rice (except in 1993, when a cool summer damaged the rice crop) (Fig. 3).

Why did the lower fertilizer N application not reduce yields? The wide adoption by farmers of "Koshihikari", a rice variety with a good flavor, seems to be one of the reasons. With a rice surplus, consumers became fussier and began to prefer rice with a good flavor. "Koshihikari" is rather an old variety. It attains its maximum yield at a lower level of N application than high-yielding varieties. The standard N application for "Koshihikari" is only 60 - 70 kg N/ha. The area planted in "Koshihikari" increased from 5.9% in 1970 to 35.5% in 2000.

Although nowadays there is not so much overuse of fertilizer N for rice, the situation has not changed for crops in upland fields (Fig. 4). Japan has greatly reduced the production of cereals and legumes in upland fields. Most wheat, barley, soybean etc. are now imported. The main crops in upland fields are vegetables, fruits and flowers. These require more N fertilizer than cereals and legumes. Therefore, water pollution by fertilizer has become serious in many upland areas.

AMOUNT OF NITROGEN APPLIED TO DIFFERENT CROPS IN JAPAN

Industry and mining have both caused serious water pollution in the past in Japan. There was a peak around 1970. Since then, their share in the load of water pollutants has steadily decreased, so that at present it is only

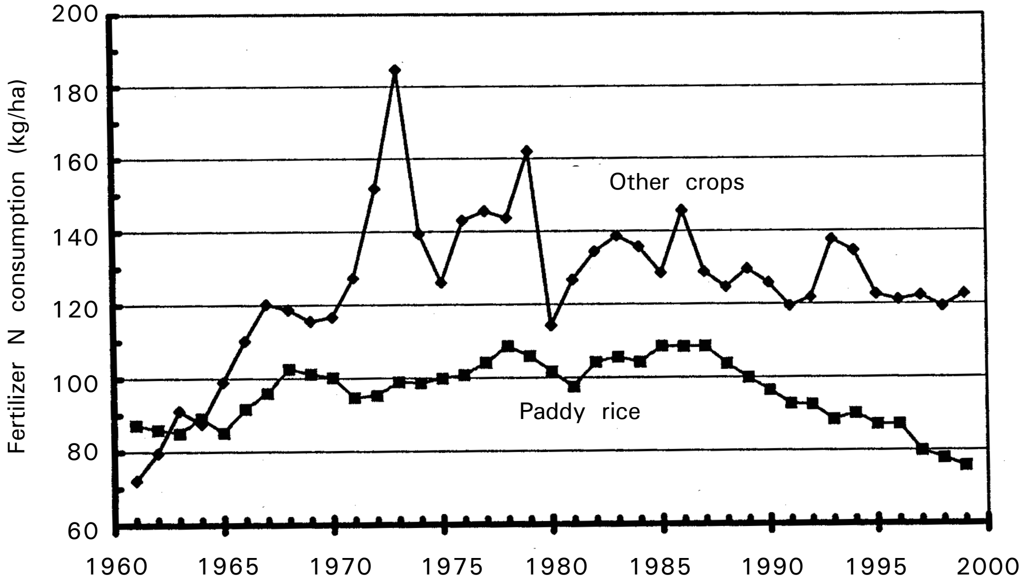

Fig. 4. Changes of fertilizer N consumption in paddy rice and other crops in Japan

Source: Nishio 2002

one-third. Water pollution caused by agriculture, however, became evident from the 1970's. Its share has now increased to one-third of the total load.

Many studies report the heavy pollution of groundwater with nitrate in rural areas, especially those producing vegetables, fruits, tea and livestock. It is clear that the heavy application of fertilizers and the inappropriate management of animal wastes are the causes of nitrate pollution of underground water. However, data on the actual amounts of nitrogen applied to crops are generally difficult to collect in rural areas.

In 1998, therefore, the Statistics and Information Department of the Ministry of Agriculture, Forestry and Fisheries (2000) surveyed the actual amounts of chemical fertilizer, organic fertilizer and compost applied to various kinds of crops (not including forage crops). This information was obtained by interviews with 16,158 farmers.

Three parameters were calculated for each kind of crop.

- The mean amount of total mineral N supplied to the plants during the growing period, in the form both of chemical fertilizer N, and mineralized N from organic fertilizer and compost;
- The mean amount of N absorbed by the above-ground part of the plants (absorbed N);
- The mean amount of N not absorbed by the plants, calculated by subtracting 2 from 1 (non-absorbed N).

In the calculation, natural N supplied by irrigation water, biological nitrogen fixation or soil organic matter was ignored. For this reason, the non-absorbed N of paddy rice, pulses and sweet potato had a negative value (Fig. 5).

It was noticed that the excessive use of N was very common in the production of vegetables, fruits and industrial crops. The mean level of non-absorbed N was especially high in outdoor celery (732 kg/ha), outdoor eggplant (483 kg/ha), outdoor cucumber (482 kg/ha), greenhouse celery (455 kg/ha), tea plants (350 kg/ha), Japanese pear (317 kg/ha), greenhouse eggplant (314 kg/ha) and greenhouse cucumber (311 kg N/ha) (Fig. 5). These values were only the average. Many farmers applied much more N than the mean value. Fertilizer applications were so high that they depressed plant growth and yields, making the amount of non-absorbed N even higher.

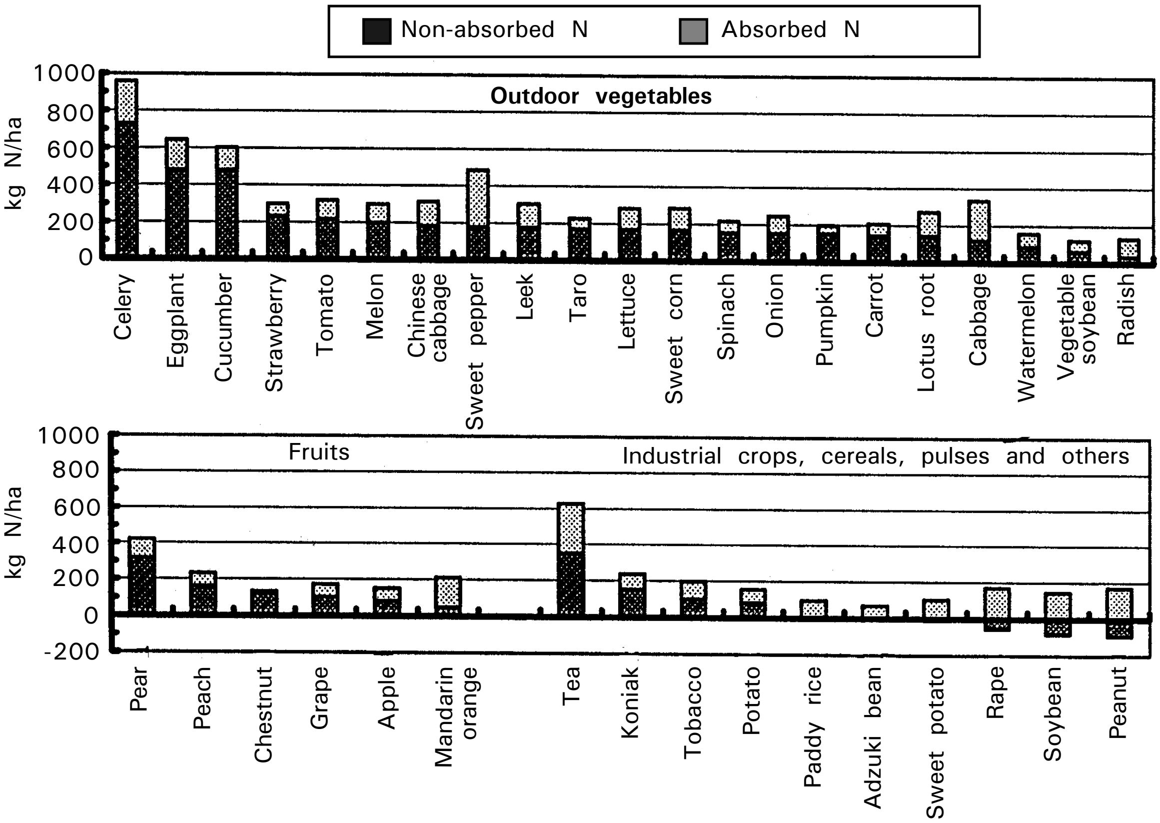

Fig. 5. Major crops in Japan and the meat amounts of absorbed N and non-absorbed N

Source: Nishio 2001a

ASSESSING THE RISK OF NITRATE POLLUTION OF GROUNDWATER

The standard N fertilization load, which is the mean amount of non-absorbed N associated with different crop species, was determined. Any negative value was defined as zero (Table 1).

The standard N fertilization load is a very effective way of assessing the risk of nitrate pollution of groundwater. Data on the area planted in each type of crop in each municipality was collected from the agricultural census, which is conducted every 5 years. The total N fertilization load in each municipality was calculated by multiplying the area of each crop by the standard N fertilization load. The N load index was calculated by dividing the total N fertilization load by the total area of the municipality. The result was seen as an indicator of the risk of groundwater pollution by nitrate from applied N fertilizer.

Fig. 6 shows an example of a calculation made in the southern and western parts of Ibaraki Prefecture. The data on wells with too high a nitrate concentration were obtained by researchers of the Ibaraki Prefectural Institute of Public Health in 1988. The data refers to 800 wells in 17 municipalities. The N load index was calculated from the agricultural census of 1975, 1980 and 1985. The correlations between the two variables were highly significant ($P<0.01$).

The western part of Ibaraki Prefecture is an important center of production of Chinese cabbage and Japanese pear, with a high N load. The southern part is urban, and the area of agricultural land is relatively small. In the most polluted municipality, 86% of the wells had a higher nitrate-N level than the 10 mg/mL which is the maximum level for drinking water. Fig. 6 clearly shows that excess application of N is the main cause of nitrate pollution of groundwater in rural areas.

Many municipalities have the problem of nitrate pollution of groundwater. Kakamigahara City in Gifu Prefecture uses groundwater for its

Table 1. Standard N load of different crops (kg N/ha)

Crop	N load	Crop	N load	Crop	N load
Cereals, Industrial crops					
Cereals, Sweet potato	0	Onion	155	Mandarin orange	50
Pulses	0	Radish	39	Peach	162
Potato	84	Carrot	146	Chestnut	124
Pulses, green	66	Taro	174	Greenhouse tomato	231
Tobacco	104	Lettuce	173	Greenhouse cucumber	311
Tea	350	Sweet pepper	182	Greenhouse eggplant	314
Other industrial crops*	25	Other outdoor	100	Greenhouse sweet pepper	9
		vegetables*		Greenhouse watermelon	153
Vegetables				Greenhouse strawberry	224
Tomato	220	**Fruits**		Greenhouse melon	37
Cucumber	482	Apple	85	Other greenhouse	
Eggplant	483	Field Watermelon	89	vegetables	100
Chinese cabbage	182	Grape	106	Mulberry	25
Cabbage	121	Field strawberry	234		
Spinach	157	Japanese pear	317		
Leek	179				

*: Assumed value
Source: Nishio 2001b

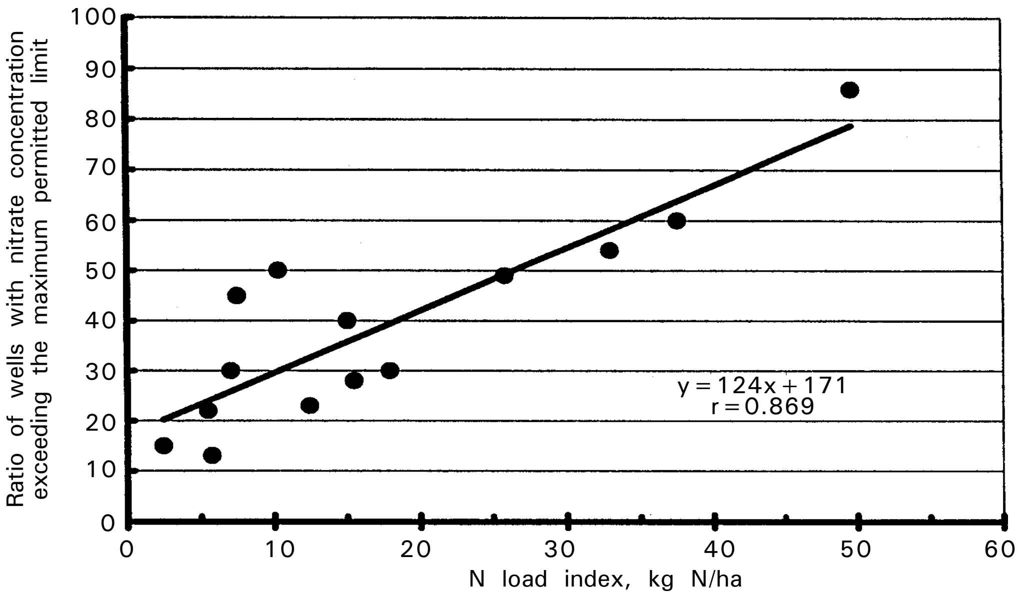

Fig. 6. Relationship between N load index (1980) and ratio of wells with a nitrate concentration exceeding the maximum limit (1988) in the southern and western parts of Ibaraki Prefecture

Source: Nishio 2001b

public water supply. In the past, sweet potato and mulberry (for sericulture) were dominant in the city. After 1968, this changed to two crops of carrot each year.

Nitrate pollution of groundwater became apparent in 1971, and got worse each year. The city and prefectural authorities investigated the cause of the pollution and concluded that the overuse of fertilizer on carrot crops was probably the main cause. They recommended that farmers reduce fertilizer N by 30%, and replace some of the chemical fertilizer with organic fertilizers which release mineral nitrogen slowly.

This change resulted in an improvement of carrot quality without any loss of yield. The efficiency of N absorption by carrot increased from 30% to 45%, while the physiological disorders caused by excess fertilizer were reduced. The change also resulted in a reduction in the area with polluted groundwater (Fig. 7).

The N load index was also effective in explaining the problems of Kakamigahara City. Table 2 shows the N load indices of eight areas in the city calculated from the agricultural census of 1980. A high load was found in the Unuma area, where the groundwater pollution area was also concentrated. In the Unuma area, 48% of the N load originated from fertilizer applied to carrot (Table 3).

Changes in the N load in the Unuma area from 1975 to 1995 were calculated using the standard N load for various crops shown in Table 1. As Fig. 8 shows, the N load increased up to 1980, but then fell to much lower levels. This explains the reduction of the polluted zone in Fig. 7, taking into account the time lag between reducing the amount of fertilizer and an improvement in water quality.

It has been estimated that 49 - 86% of non-absorbed N applied to upland soils is leached out into the groundwater. The amount of N washed out in runoff is very small (<1%) in Japan (Ogawa 1979). Most municipalities in Japan have an annual rainfall of 1,000 - 2,800 mm (1,740 mm on average), and evapotranspiration of 600 - 1,000 mm. If non-

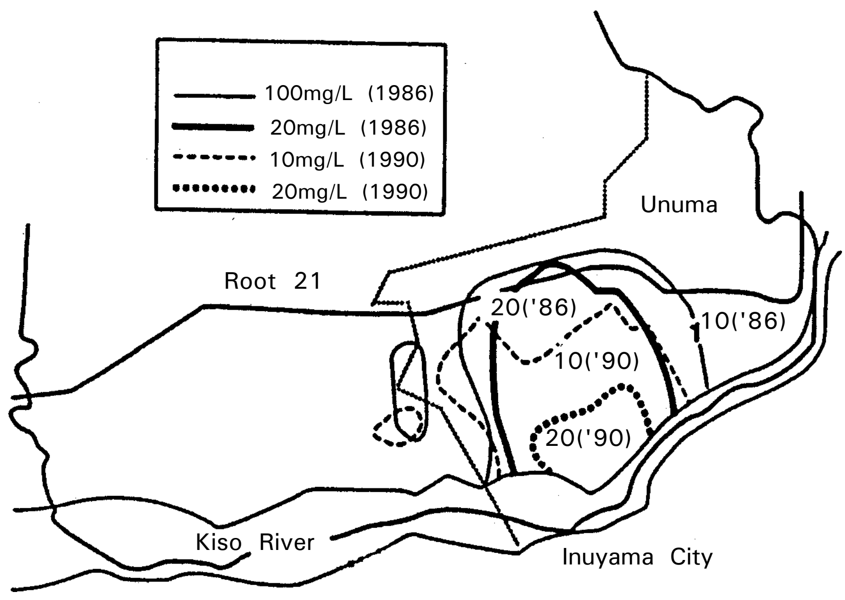

Fig. 7. Reduction of area with groundwater polluted with nitrate by improved fertilizer management, Kakamigahara City, Gifu Prefecture

Source: Kitajima 1994

Table 2. N load indices of eight areas in Kakamigahara City, Japan

	N load index (kg N/ha)
Unuma	25.0
Suhara	12.7
Saraki	11.6
Naka	7.4
Miyamae	7.4
Kkami	6.1
Nakaya	4.1
Average for whole city	12.7

Table 3. Share of N load according to crop in the Unuma area, 1980

	Share (%)
Carrot	48.1
Taro	17.3
Chinese cabbage	9.1
Outdoor tomato	5.7
Japanese pear	5.3
Others	14.6

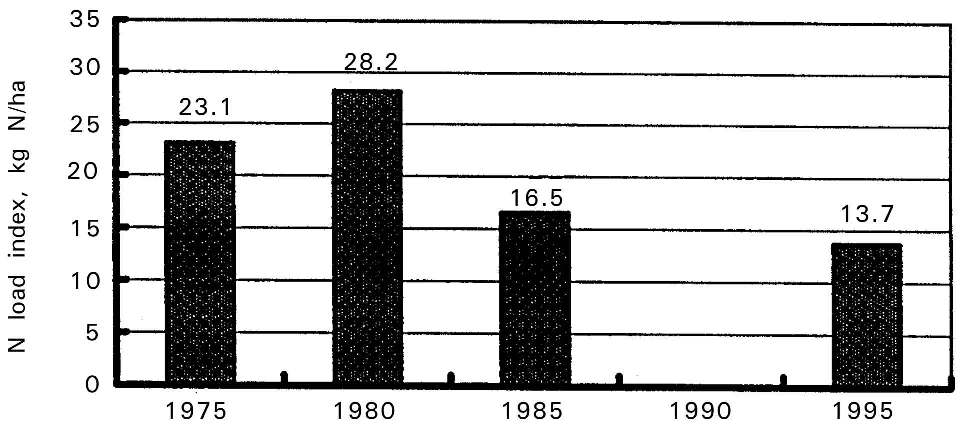

Fig. 8. Change in N load in the Unuma area of Kakamigahara City, Japan

absorbed N is 200 kg/ha, then 98 - 172 kg N may leach into groundwater, giving 9.8 - 28.7 mg of nitrate per liter of groundwater, Therefore, a drastic reduction in the level of non-absorbed N is needed, in order to improve the quality of underground water in rural parts of Japan.

CONCLUSION

Although chemical fertilizers are needed to increase food production, serious water pollution is occurring in countries with a high level of fertilizer use, as the result of excess applications of fertilizers. Asian countries such as Korea, China, Japan, and recently Vietnam, are applying a very high level of fertilizer N per hectare, for both short-term and perennial crops.

It seems likely that serious water pollution may be occurring in all these countries. Farmers are generally afraid of a yield reduction if they apply less fertilizer. In practice, excessive fertilizer use tends to result in yield losses, rather than the maximum yield. As the relationship between yield and fertilizer N in EU countries and Japan shows, high yields can be maintained even when fertilizer applications are reduced.

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