

SOIL MANAGEMENT FOR THE CONSERVATION OF SOIL NITROGEN

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ABSTRACT

It is impossible simply to quantify soil nitrogen fertility. Soil nitrogen fertility should be recognized as the integrated function of various processes in the nitrogen cycle in a soil-plant system, and of the environmental factors affecting them. Nitrogen mineralization is the most important process in the nitrogen cycle. In Japan, nitrogen mineralization is mainly governed by temperature. A method of predicting nitrogen mineralization from temperature has recently been developed in Japan. This method has provided valuable information for the rational application of fertilizers and organic matter. In moist climates, leaching of nitrate is a cause of environmental pollution as well as low efficiency of fertilizer nitrogen. However, some deep-rooted crops can absorb the nitrate which has been leached from the plow layer and has accumulated in the subsoil. The significance of the subsoil in efficient nitrogen use is emphasized. Regarding soil management for conserving nitrogen fertility in Japan, some problems involved in the use of paddy soils for upland crops are discussed. The advantages of minimum tillage in extensive agriculture are also reviewed.

INTRODUCTION

It is very difficult to define the term "nitrogen fertility of soil". Nitrogen fertility is often assumed to be the amount of available nitrogen in the soil, but in an intensive agricultural system, a soil rich in available nitrogen is not always a soil in which high yields of good quality can be achieved. In a soil rich in available nitrogen, crop yields may be reduced by lodging, and the quality of crops is often poor because of the high nitrate content and mineral imbalance. In addition, the utilization efficiency of nitrogen fertilizer tends to be lower (Nishimune *et al.* 1982). As a result, excess nitrogen which is not absorbed by crops may be leached out and may cause environmental pollution.

As Fig. 1 shows, the flow of nitrogen in a soil-plant system is complex. Current intensive agricultural practices in developed countries tend to use a lot of fertilizer, so that control over nitrogen flow in a soil-plant system is now necessary if farmers are to produce crops of good quality and minimize environmental pollution due to the leaching of nitrate.

Cooke (1967) has stated that soil fertility is the capacity of soil to produce the crops desired.

According to this concept, soil nitrogen fertility can be defined as the ability of soil to control the flow of nitrogen in a soil-plant system for the production of the crops desired. In other words, soil nitrogen fertility can be recognized as the function of various factors affecting the flow of nitrogen in a soil-plant system.

Soil Nitrogen Fertility = f (mineralizable nitrogen, other chemical properties, physical properties, agro-climatic factors,...)

This paper will focus on the evaluation of soil nitrogen fertility based on current research into nitrogen mineralization, and will discuss some examples of soil management in Japan, with an emphasis on nitrogen fertility.

SOIL NITROGEN FERTILITY: OPTIMIZATION OF NITROGEN FLOW IN A SOIL-PLANT SYSTEM

As mentioned in the introduction, soil nitrogen fertility comprises various soil processes and environmental factors, which make it difficult to

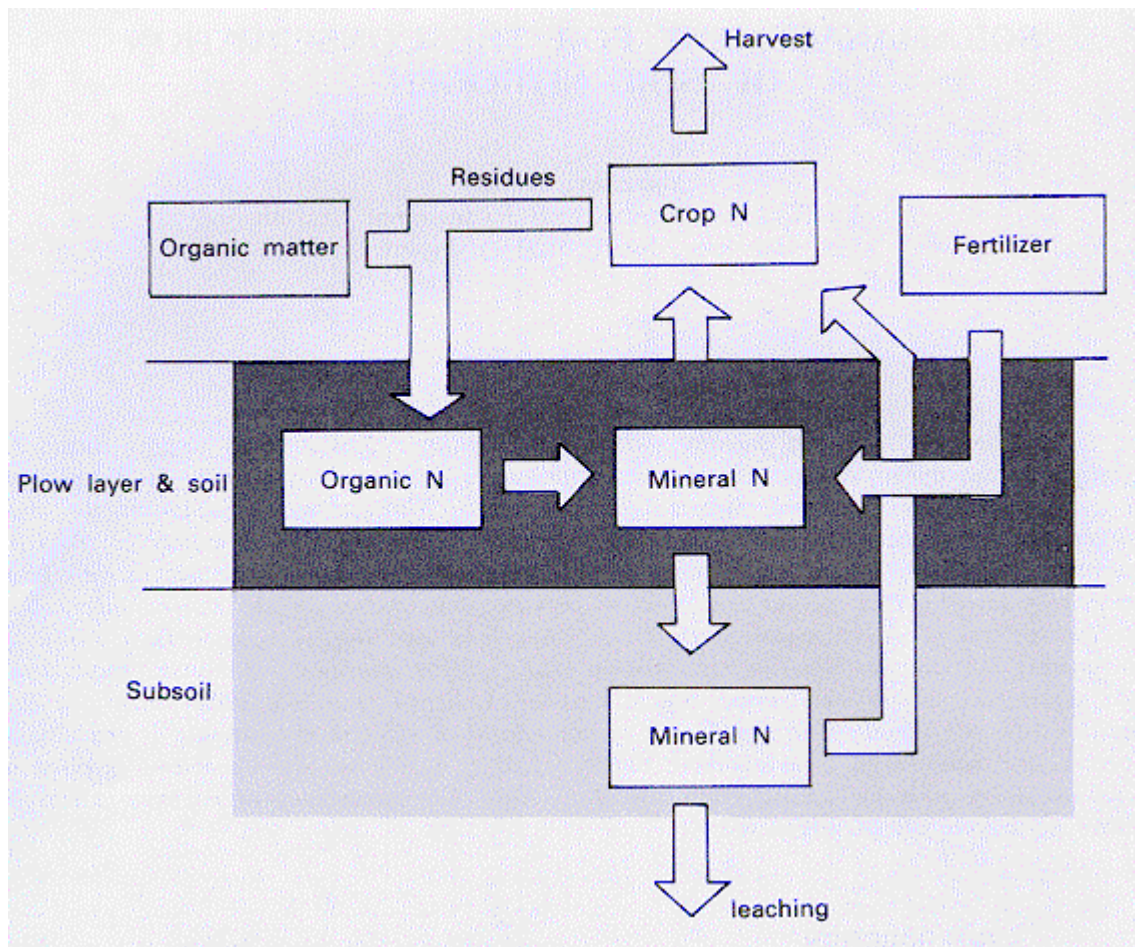


Fig. 1. Flow of nitrogen in a soil-plant system

quantify. Some of the processes comprising nitrogen fertility are discussed in the following section.

Mineralization of Soil Organic Nitrogen: Effectiveness of Nitrogen

Mineralization Parameters

Of the various processes involved in soil nitrogen fertility, mineralization of nitrogen from soil organic matter is the most important. In Japan, which stretches a considerable distance from north to south and displays a wide range of climates, from subtropical to subarctic, the main factor governing nitrogen mineralization is temperature. Several methods based on temperature have been developed for predicting nitrogen mineralization of soils (Stanford *et al.* 1972, Yoshino *et al.* 1978). Recently, Nitrogen Mineralization Parameters (NMP)

have received considerable attention from Japanese soil scientists (Tohoku Soil Nitrogen Mineralization Research Group 1988). The NMP can be determined by analyzing the nitrogen mineralization curves of soil on the basis of kinetic models (Sugihara *et al.* 1986). The NMP are the parameters for characterizing the nitrogen mineralization process in relation to temperature, and their use has made it possible to predict nitrogen mineralization from temperature (Fig. 2) (Konno *et al.* 1986). Predicted nitrogen mineralization agrees well with actual observations in upland fields in Japan with a moist climate (Saito *et al.* 1987, 1988). That this methodology has been extensively applied to paddy soils to improve fertilizer management (Ando *et al.* 1989, Kitada 1990, Ueno *et al.* 1990a, 1990b, Yamamoto *et al.* 1986) indicates its practical value. Furthermore, the NMP can be applied to predict long-term changes in the level of mineralizable N in the soil.

To apply the NMP method under dry conditions, the moisture factor in mineralization should be taken account. The relationship between mineralization and soil moisture as analyzed by Stanford *et al.* (1974) or Toriyama *et al.* (1988) may be incorporated into the NMP method.

Utilization Efficiency of Soil Nitrogen

To minimize environmental pollution due to leaching of nitrate N, not only fertilizer nitrogen but also nitrogen mineralized from soil should be efficiently absorbed by crops. Although the actual uptake of fertilizer nitrogen by the crop can be determined by the ¹⁵N tracer technique, it is not easy to evaluate the absorption efficiency of soil nitrogen. As stated in the previous section, the rate of soil mineralization can be predicted by the NMP method. A comparison between the estimated amount of mineralized nitrogen (based on the NMP) and the uptake of soil nitrogen (estimated by the ¹⁵N technique) now makes it possible for the first time to estimate the percentage of soil nitrogen absorbed by the crop. The experimental results for corn are shown in Fig. 3 (Saito *et al.* 1987). This percentage for corn was more than 80% when the amount of mineralized nitrogen during a growing season was less than 130 kg N/ha, while it decreased when the amount of mineralized N was higher than 130 kg N/ha. This indicates that mineralizable nitrogen in soil may not be efficiently used by crops if there is too much of it. In this experiment, the absorption percentage of fertilizer nitrogen ranged from 28 to 66%. It is noteworthy that the crop significantly depended on fertilizer nitrogen, even when the amount of nitrogen mineralized from soil exceeded crop requirements.

Thus, the application of the NMP method to ¹⁵N fertilizer trials can provide valuable information for the sound management of soil fertility from the viewpoint of efficient use of nitrogen.

Leaching of Nitrate N: Significance of the Subsoil

In moist climates, nitrate N in the plow layer easily moves downwards. However, this nitrate N tends to accumulate in the layer beneath, from which some crops can absorb the mineral nitrogen. Crops with a deep root system, such as corn, can efficiently absorb nitrogen accumulated in the subsoil (Saito 1987, 1990). For such crops, the effective depth of soil should be recognized as approximately 1 m or more. The physico-chemical

properties of the subsoil influence the uptake of mineral nitrogen from the subsoil, so that if the elongation of roots in the subsoil is inhibited by poor soil properties, mineral N accumulating in the subsoil cannot be absorbed and may be leached out (Table 1) (Saigusa *et al.* 1983). Therefore, the physico-chemical properties of the subsoil should be taken into account when planning fertilization and soil management.

Modern, intensive agricultural practices make it possible to ameliorate poor chemical and physical properties of soil. However, in most cases, amelioration is limited to a shallow layer of soil at the surface. More attention should be paid to ameliorating the subsoil.

CONSERVATION OF SOIL NITROGEN FERTILITY BY ORGANIC MATTER APPLICATIONS

Organic matter applications are believed to be essential for the conservation of soil nitrogen fertility. The relationship between soil management and the factors comprising fertility is shown in Table 2 (Takai *et al.* 1977). This Table clearly shows that various functions of organic matter are closely related to overall soil fertility.

In Japan's intensive agriculture, many scientists are worried that both the decline in the application of organic matter, and heavy applications of cattle manure from animal husbandry, are causing a deterioration in soil fertility and environmental pollution. It is necessary to apply the optimum rate of organic matter, and to maximize the functions of organic matter in enhancing soil fertility. For applications of organic matter to be optimum, it is necessary to quantify organic matter decomposition so we can predict it. A special project on this topic was conducted by the Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan (Research Council Secretariat of MAFF 1985).

Since the decomposition of organic matter (or mineralization of organic nitrogen) is governed by agro-climatic factors, mainly temperature, it is difficult to make general recommendations for optimal rates of applied organic matter based on field trials. However, if the nitrogen mineralization parameters of applied organic matter can be obtained, these make possible quantified recommendations under different climatic conditions*. These parameters can be determined by incubation experiments in the laboratory.

On the basis of these parameters and meteorological data, the rate of mineralization of organic matter under different climatic conditions can be

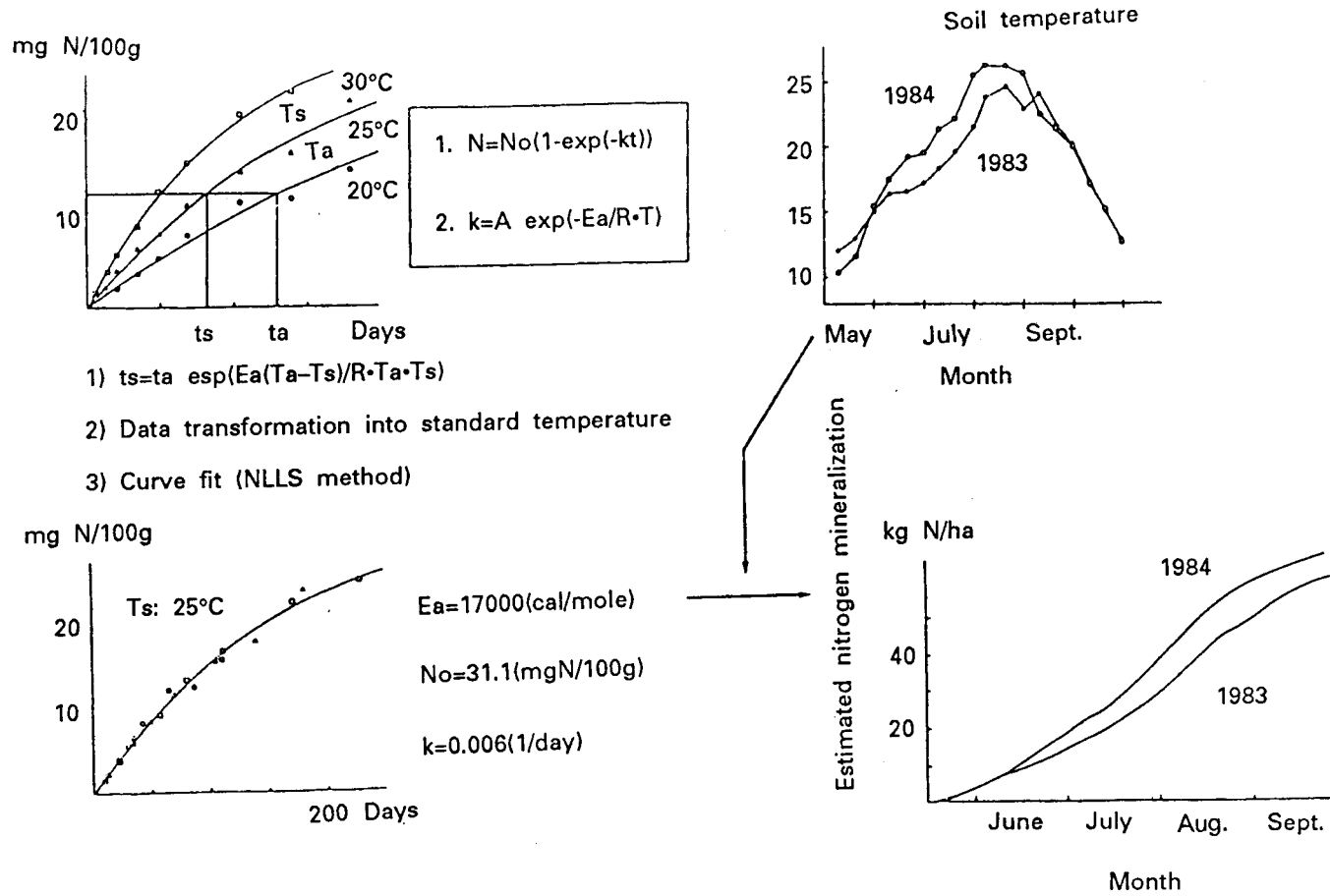


Fig. 2. Kinetic analysis of nitrogen mineralization curve, and estimation of nitrogen mineralization based on the kinetic parameters

Source: Sugihara *et al.* 1986, Konno *et al.* 1986

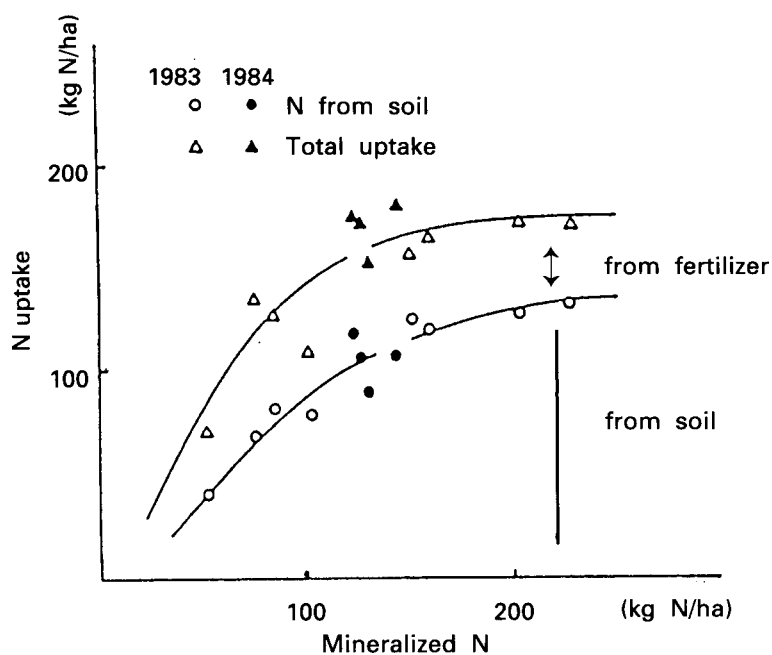


Fig. 3. Nitrogen uptake of corn, in relation to mineralized soil nitrogen estimated on the basis of soil temperature. Amount of nitrogen derived from fertilizer was determined with ^{15}N labeled fertilizer

Source: Saito and Ishii 1987

Table 1. Effect of subsoil acidity on growth and nitrogen uptake of barley

Subsoil	Properties of subsoil					Yield (g/m ²)	Utilization efficiency of fertilizer N (%)	
	pH (H ₂ O)	pH(KCl)	texture	Y1	clay minerals		Basal	Top dressing
Kawatabi	4.6	4.2	CL	11.8	2:1 clay	397	6.5	75.4
Zaou	5.5	5.0	CL	4.1	allophane	694	48.2	81.3

In fields with concrete surround, the subsoil (15-40 cm) was replaced by two types of subsoil (Kawatabi and Zaou), over which was placed the original plow soil (0-15 cm of Kawatabi). The utilization efficiency of fertilizer-N was determined by means of ^{15}N labelled ammonium sulfate (Basal; 10 g N/m², Top; 4 g N/m²)

Source: Saigusa *et al.* 1983

Table 2. Relationship between soil management and various aspects of soil fertility

Factor	Soil management			
Chemical properties				
Nutrient supply	○			
Slow and continuous supply of nutrients	◎			
Buffer action (pH, Eh, EC etc.)	◎			
Absence of toxic substances	○			
Physical properties				
Water supplying capacity	○			
Drainage, percolation	○			
Aeration	○			
Tillage	◎			
Resistance to erosion	◎			
Biological properties				
Promotion of saprophytic activity (organic matter decomposition etc.)	◎			
Suppression of pathogens and pests	○			
	Organic matter application	Sub-soiling	Water management (flooding, irrigation)	Soil amendments (CaCO ₃ , Fused P, etc)
				Chemical fertilizer
				Fertilization
				Crop rotation
				Slow-release fertilizer

◎ : Close relationship, ○ : Weak relationship

Source: Takai and Miyoshi 1977

predicted (Fig. 4) (Konno *et al.* 1986, Sugihara *et al.* 1988). For countries which have diverse climatic conditions, this type of prediction is useful in planning application rates of organic matter in different regions. Similarly, predictions of nitrogen mineralization in the soil itself can provide valuable information on long-term changes in soil nitrogen fertility. According to this idea, a simple model analysis of a long-term experiment studying manure applications was made (Saito *et al.* 1986). This concluded that the application of 20 t/ha of dairy cattle manure was best, in terms of maximizing the productivity of corn without environmental pollution, in Japan's cool, temperate climate.

Although many problems still remain to be solved, i.e. the effect of the cropping system on the parameters etc., a prediction of nitrogen mineralization rates is a valuable aid in recommending application rates of organic matter in order to conserve soil nitrogen fertility.

SOIL MANAGEMENT AND NITROGEN FERTILITY: SOME EXAMPLES FROM JAPAN

In this section, some advances in soil management aimed at the conservation of nitrogen fertility are briefly discussed.

Wetland Rice Based Cropping System: Rotation of Wetland Rice and Upland Crops

Rice is the main crop in Japan, as in other East Asian countries, and is grown on a large proportion of Japan's arable land. In order to improve the efficiency of land use, wetland-rice based cropping systems, including the rotation of wetland rice with upland crops, have been introduced (Shiroshita *et al.* 1960).

In paddy soils under crop rotation, upland crops often suffer from moisture stress due to the physical condition of the soil (Moroyu 1983). Flooding soil for rice cultivation suppresses organic matter decomposition. When paddy soil is then used for upland crops, the accumulated mineralizable nitrogen is rapidly decomposed and becomes available for these upland crops. On the other hand, the rotation from wetland to upland oxidizes not only the plow layer but also the subsoil. When rice is subsequently grown in the same field again, rice can elongate its roots to a considerable depth and absorb a large quantity of nutrients (Fig. 5) (Kaneta *et al.* 1989).

Since decomposition of organic matter is

much faster under upland conditions than under flooded ones, the nitrogen availability of the soil decreases rapidly after soil is rotated from wetland to upland use (Fig. 6) (cited in Maeda 1987). Inevitably, repeated rotation may exhaust the level of organic matter in the soil (Moroyu 1983). Therefore, the introduction of upland crops such as legumes, which contribute to an increase in nitrogen fertility, should be considered in such a cropping system.

Given the present situation of agriculture in Japan, farmers are forced to rotate paddy soils even if they recognize that soil conditions are unsuitable for upland crops. Modification of the rotation system where this is the case, using the present intensive, mechanized agricultural practices, has thus been studied. For instance, in a heavy clayey polder soil in Ohgata, Akita prefecture, minimum tillage without puddling was used for wetland rice (Kaneta *et al.* 1991). This practice prevented compaction of the plow layer, and improved drainage when the field was rotated to upland crops, so that a higher yield of subsequent wheat was recorded than with conventional tillage. The change in nitrogen fertility in this management system is now under investigation, but crops are expected to utilize nitrogen more efficiently.

Minimum Tillage

In Hokkaido, in northern Japan, large-scale mechanized agriculture for upland crops has been developed for a cool climate. Deep plowing was believed to be necessary for maximizing crop yield, because it increased the soil volume within which crop roots could elongate. In fact, as the size of tractors became larger, the average depth of plowing increased and has now reached more than 30 cm. However, expanding the plow layer as a result of deep plowing results in the dilution of soil nutrients, so that much more fertilizer is needed to get the same yields as before. Furthermore, the repeated traffic of large tractors causes serious compaction of the soil.

As oil prices increased, therefore, the energy intensive practice of deep plowing was reconsidered. To develop a sustainable soil management system less expensive in energy, the use of minimum tillage (MT), with such practices as shallow rotary tilling and chiselling, was examined in Hokkaido and compared with conventional tillage by plow (Hatanaka *et al.* 1987, Ogawa *et al.* 1988a, 1988b, Watanabe *et al.* 1987).

The characteristics of minimum tillage (MT) found in several field trials are summarized as follows:

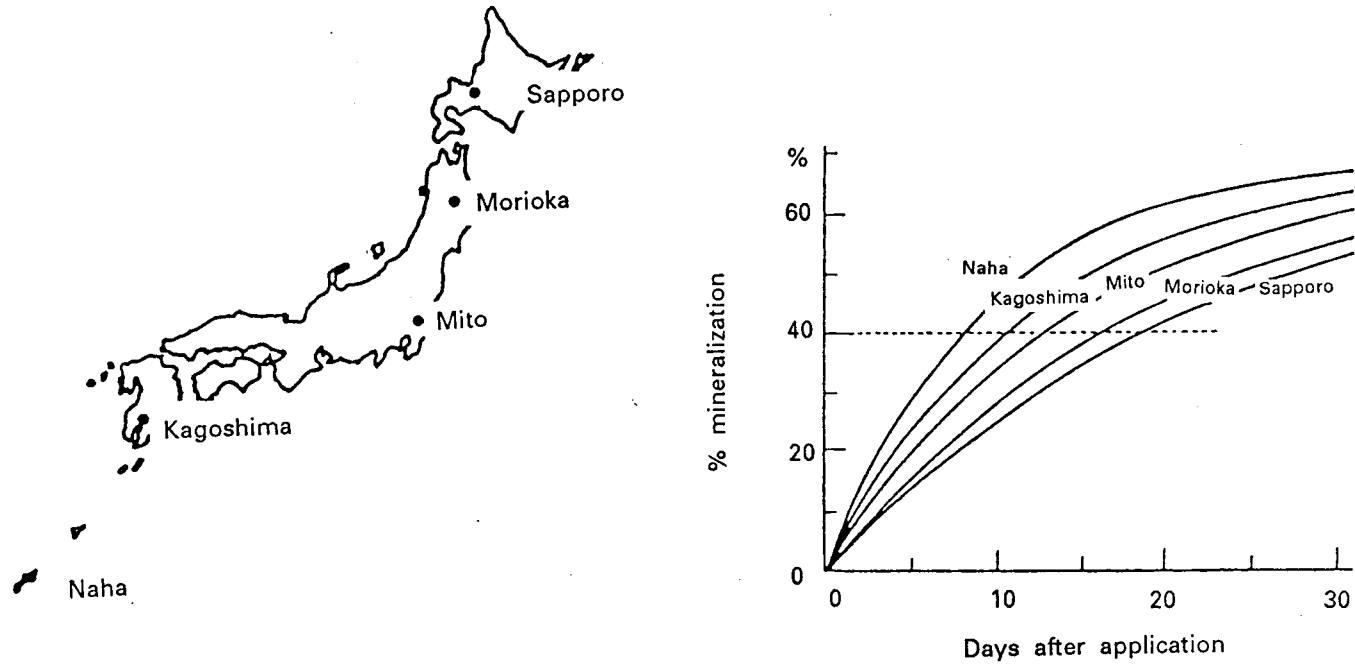


Fig. 4. Estimate of nitrogen mineralization from organic matter (sewage sludge) applied to soil at different locations. Assuming that the organic matter is applied on 1st May at various sites, nitrogen mineralization was estimated from the parameters determined by the laboratory incubation experiment and mean soil temperature at these sites

Source: Konno and Sugihra 1986

- In many cases, crop yields under MT increased, or were comparable to those grown by conventional tillage.
- The rate of nitrate movement through soil profile was slower, so that utilization efficiency of fertilizer nitrogen was higher than in conventional tillage (Table 3). Moisture stress was alleviated with MT, so that germination of seeds and the subsequent growth of young plants were promoted.
- Soils were slightly compacted under MT, but root elongation was not suppressed. In a heavy clayey soil, deterioration of soil structure in the subsoil due to traffic by a tractor was prevented by using MT.
- MT reduced wind erosion.
- Decomposition of organic matter was suppressed, so that mineralizable nitrogen accumulated.

Thus, MT affects not only the physical

condition of the soil but also its chemical and biological condition. Although MT does not always give good results, it is a promising system of management from the viewpoint of efficient use of nitrogen.

CONCLUSION

It is impossible to draw a simple conclusion from the many aspects of soil nitrogen fertility discussed here. Soil nitrogen fertility is relative. In other words, nitrogen fertility greatly depends on the type of crop, and on the type of soil. One crop may prefer a soil rich in available nitrogen, while another may not. The best way to evaluate the nitrogen fertility of soil is to quantify each process involved in nitrogen fertility, and to integrate these. Although a methodology for such integration has not yet been fully developed, the simulation model for nitrogen flow in a soil-crop system seems promising. The modelling approach makes possible optimum soil management for the conservation of nitrogen fertility.

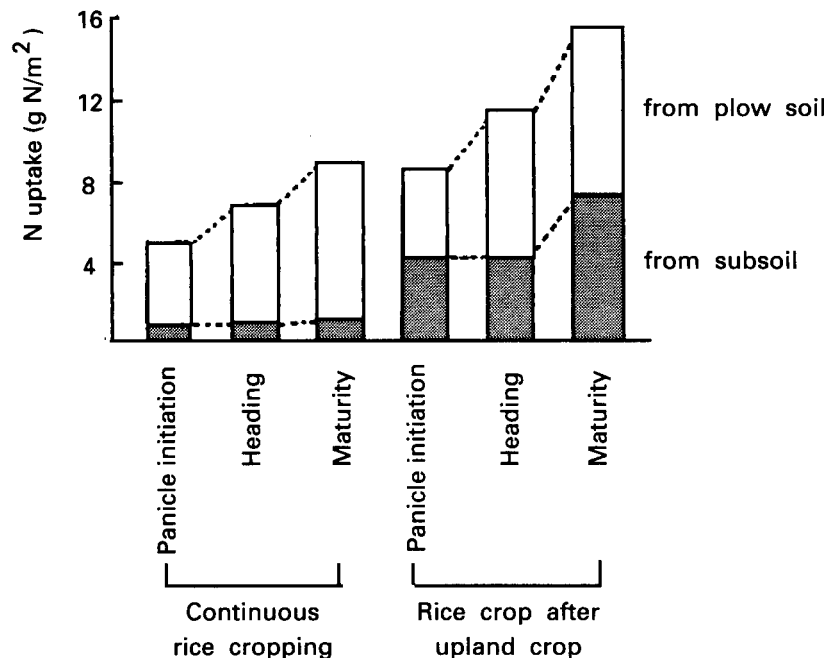


Fig. 5. Effect of crop rotation on nitrogen uptake of rice from plow soil and subsoil in a heavy clay polder soil

Source: Kaneta *et al.* 1989

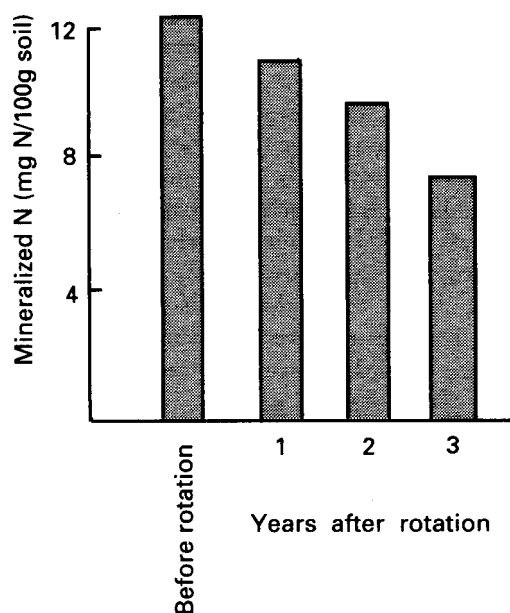


Fig. 6. Decrease in mineralizable N after the use of a brown lowland paddy soil for rice rotated with upland crops. The amount of mineralizable N was determined by incubating the soil at 30°C for 1 week under waterlogged conditions

Table 3. Effect of minimum tillage on growth and nitrogen uptake of sweet corn

Method of tillage	Dry matter (t/ha)*	N uptake (kg N/ha)*	Recovery rate (%)*	Yield (t/ha)
Shallow rotary tillage to 5 cm depth	9.06	183	104	12.9
Shallow rotary tillage to 10 cm depth	7.49	147	80	12.4
Conventional tillage	6.45	134	71	11.4

Recovery rate (%) = (Uptake N with fertilizer - Uptake N without fertilizer) / (fertilizer N) x 100

* Measured on August 7

Source: Hatanaka and Shiozaki 1987

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DISCUSSION

Q. (Achmad M. Fagi)

Recently, there has been growing concern about minimum tillage and the different results it gives. What were the characteristics of the places where minimum tillage gave “good” results?

A. Whether minimum tillage gives good results or not depends on the crop, the soil and climatic factors. In Japan, it sometimes gives good results and sometimes does not. It is still difficult to know what kind of minimum tillage to apply in particular areas. A great deal more research is needed.

Q. (John C.W. Keng)

When you refer to minimum tillage, I can understand why you feel that it saves on energy compared to conventional tillage, but how can it save on fertilizer?

A. With minimum tillage, the soil profile is very shallow, and the nutrients accumulate in this shallow layer. When soil is ploughed, the available nutrients in the soil profile are more dispersed in a deeper layer.

Q. (John C.W. Keng)

Crop growth is based on the total uptake of nutrients. In conventional tillage, would not the greater root mass mean a greater uptake of nutrients?

A. No, the plant uptake of nutrients depends on the soil nutrient concentration. If we apply the same amount of fertilizer, the concentration of nutrients in the soil solution is lower under conventional tillage than with minimum tillage.

Q. Your data indicates that when corn plants are at an early growth stage, the mineral N is leached out of the surface soil into the subsoil, and cannot be used because the roots of the young seedlings are too shallow. How should the soil be managed to prevent this?

A. In June and early July, the corn plant is still very small and its roots cannot penetrate into the subsoil. At this stage the mineral N has already been leached out of the topsoil. However later on, in early August, the plants grow much bigger and can absorb N from the subsoil.

Q. (Henry P. Sanmonte)

I am concerned about the graph (Fig. 3) showing that with an increase in mineralized soil nitrogen to 100 and 200 kg N/ha, while there was an increase in the uptake of mineralized N there was still an increase in the uptake by plants of fertilizer N. Does this mean that we cannot substitute completely?

A. It depends on the agro-climatic factors. The experiments shown in Fig. 3 were carried out in northern Japan, where in early spring N mineralization is not sufficient to support plant growth because the temperature is very low. In early spring it is necessary to apply concentrated fertilizer N placed near the seedlings. In the early stages of growth, therefore, crops (especially corn) absorb fertilizer N. Later in the growing season, plants can absorb the soil nitrogen from all parts of the soil.

Comment (Henry P. Sanmonte)

If the nitrogen originating from mineralized N is not absorbed, a great deal of it will be lost.