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# ESTIMATION OF SOIL NITROGEN MINERALIZATION IN CORN-GROWN FIELDS BASED ON MINERALIZATION PARAMETERS

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The applicability of a new method of estimation of soil nitrogen mineralization based on nitrogen mineralization parameters (NMP) was examined in concrete-framed fields. In eight plots in 1983 and four plots in 1984, corn (*Zea mays* L.) was cultivated. The fresh soil samples collected before sowing were incubated at three temperature levels, and three kinds of NMP ($N_0$, nitrogen mineralization potential; $k$, mineralization rate constant; $E_a$, apparent activation energy) were determined by the kinetic analysis of the nitrogen mineralization curves. The amount of mineralized nitrogen during a growing season was estimated based on NMP with adjustments for the field soil temperature. The uptake of nitrogen by corn from soil nitrogen was determined by the use of $^{15}N$ labeled fertilizer. When the estimated amount of mineralized nitrogen was less than 130 kg/ha, this value agreed with the measured one. These findings indicate that the use of NMP was effective for the estimation of nitrogen mineralization under field conditions. To apply this method for a soil testing program, some problems still remain to be solved. The characteristics of NMP obtained are also discussed.

*Key Words:* soil temperature, mineralization rate constant, nitrogen mineralization potential, activation energy.

If the soil nitrogen mineralization rate under field conditions could be estimated based on weather information, higher yields of crop could be obtained and nitrogen fertilizer could be used more effectively and economically. For this purpose, nitrogen mineralization simulation models based on soil incubation experiments have been investigated. In this decade, much attention has been devoted to the applicability of these models under field conditions. However, field applicability was hitherto examined under unplanted conditions (*2*, *17*) or planted conditions without nitrogen fertilization (*5*, *10*, *20*). Thus the information under conditions in which crops are normally grown is limited.

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Recently KONNO and SUGIHARA (7) proposed a method of estimation of nitrogen mineralization based on three kinds of nitrogen mineralization parameters (NMP), *i.e.* nitrogen mineralization potential ($N_0$), mineralization rate constant ($k$), and apparent activation energy ($E_a$), which are determined by means of the kinetic analysis of the nitrogen mineralization curves obtained at three temperature levels (*16*). The kinetic analysis is in general the same as that proposed by Stanford and co-workers (*13*, *14*). However, the calculation procedure for determining NMP was much improved and can give more accurate values for the NMP. To evaluate the applicability of the method developed by KONNO and SUGIHARA (7) under field conditions, field experiments were carried out in 1983 and 1984.

## MATERIALS AND METHODS

*Experimental fields.* A concrete-framed field in Tohoku National Agricultural Experiment Station, Iwate-prefecture, Japan was used. In this field four kinds of surface soil were substituted for the original surface soil (approximately 30 cm depth) and placed on the subsoil of Kuriyagawa, an Ando soil. The substituted soils were Ishidoriya, an alluvial soil, Matsukawa, an granitic soil low in organic matter and two kinds of Ando soil; Toshima, low in base and Kuriyagawa, rich in base. In 1983 we used the micro-plots (2 × 3 m), in which dent corn had been continuously cultivated with and without the application of dairy cattle manure since 1978. In 1984 the other plots (5 × 5 m) in which soybean was cultivated in 1983 were used. Some properties of the soils are shown in Table 1.

*Nitrogen mineralization parameters (NMP).* Fresh moist soil, which was collected just before sowing, was incubated at 20, 25, 30°C for 140 to 210 days. The relative moisture of soil was kept at 50–55% of the maximum water holding capacity. The content of $NH_4^+$-N and $NO_3^-$-N mineralized during the incubation period was determined by the steam distillation method and the phenoldisulfonic acid method, respectively (*4*). The nitrogen mineralization curve was analyzed by the method proposed by SUGIHARA *et al.* (*16*). In this method it is assumed that the nitrogen mineralization curve corresponds to an equation of the first order reaction (Eq. (1)), and that the relation of the mineralization rate constant to the temperature follows Arrhenius law (Eq. (2)).

$$N = N_0(1 - \exp(-kt)), \tag{1}$$

$$k = A\, exp(-E_a/RT), \tag{2}$$

where $N$, $N_0$, amount of mineralized nitrogen at time $t$ and infinite time, respectively (mg N/100 g oven dried soil); $k$, mineralization rate constant (/day); $E_a$, apparent activation energy (cal/mol); $T$, absolute temperature (°K); $R$, gas constant (1.987 cal/(deg·mol)).

The following relation was obtained from Eq. (2) to transform the time for the

Table 1. Properties of the soils used.

| Year | | Soil | Texture | pH ($H_2O$) | Total N (%) | CEC (meq/100 g) |
|---|---|---|---|---|---|---|
| 1983 | 1. | Ishidoriya, alluvial soil | LiC | 5.8 | 0.13 | 18 |
| | 2. | Ishidoriya, alluvial soil, manured | | 5.7 | 0.19 | n.d. |
| | 3. | Matsukawa, granitic soil | SC | 5.0 | 0.04 | 18 |
| | 4. | Matsukawa, granitic soil, manured | | 5.2 | 0.09 | n.d. |
| | 5. | Toshima, Ando soil | L | 5.8 | 0.41 | 36 |
| | 6. | Toshima, Ando soil, manured | | 5.5 | 0.50 | n.d. |
| | 7. | Kuriyagawa, Ando soil | LiC | 5.8 | 0.65 | 35 |
| | 8. | Kuriyagawa, Ando soil, manured | | 5.9 | 0.82 | n.d. |
| 1984 | 9. | Ishidoriya, alluvial soil | LiC | 5.9 | 0.15 | n.d. |
| | 10. | Matsukawa, granitic soil | SC | 5.8 | 0.07 | n.d. |
| | 11. | Toshima, Ando soil | L | 5.8 | 0.41 | n.d. |
| | 12. | Kuriyagawa, Ando soil | LiC | 5.8 | 0.72 | n.d. |

Manured plot, 80 t/ha of dairy cattle manure was annually applied for 6 years up to 1982. n.d., not determined.

mineralization process at an arbitrary temperature ($T_a$) to that at a standard temperature ($T_s$);

$$t_s = t_a \exp(E_a(T_a - T_s)/RT_aT_s), \tag{3}$$

where $t_s$, $t_a$, time for the mineralization process at $T_s$ and $T_a$ temperatures (day).

Using the above relation the experimental results obtained at 20 and 30°C could be transformed into those obtained at 25°C (standard temperature). Curve fitting of the transformed data to the model described in Eq. (1) was performed for the determination of NMP by iteration. The fitness of the model was evaluated by the minimum AIC (Akaike's information criteria: AIC$=N \ln S+2r$; $N$, number of data set; $S$, residual sum of square; $r$, number of parameters) estimate. The smaller the AIC value, the better the fitness. The calculation was done by using the program "ENMS" (*8*).

*Estimation of nitrogen mineralization from soil temperature.* The amount of mineralized nitrogen was estimated from NMP after adjustment for the field soil temperature (*7*). The mean between the daily highest and lowest temperature at 10 cm depth was used for the daily soil temperature. The amount of mineralized nitrogen was expressed on an area basis from the bulk density of the soil and the depth of the plow layer.

*Uptake of nitrogen by corn.* Corn (*Zea mays* L.) was cultivated in the above mentioned plots without the application of manure. In 1983 the corn cv. Pioneer

P3715 was sown on May 6 at a hill spacing of 75×25 cm. In 1984 the corn cv. Pioneer P3424 was sown on May 7 at 70×20 cm spacing. Ammonium sulfate, superphosphate and potassium sulfate at the rate of 100-150-100 ($N$-$P_2O_5$-$K_2O$ kg/ha) were applied as basal and stripe dressing. To determine the amount of nitrogen absorbed from the fertilizer, $^{15}N$-labeled fertilizer was applied to a part of the plot. Plants were uprooted at successive growth stages, separated into stems, leaves and grains, weighed and prepared for chemical analysis. The nitrogen content in plants was measured by the salicylic acid digestion method (*4*), and $^{15}N$ by emission spectrometry (*9*).

Mineral nitrogen in the plow layer was measured throughout a growing season. To avoid the contamination of fertilizer (stripe dressing), the soil samples were collected from the plow layer between rows.

## RESULTS AND DISCUSSION

*Nitrogen mineralization parameters*

Analysis of the mineralization curve at three temperature levels showed that the nitrogen mineralization process in all the soils could be represented by an equation of the first order reaction as reported by many workers (*1, 13, 16*). Since it was reported that a model based on double exponential equations was more suitable (*3*), we examined the fitness of the double compartment model to the data. However, this model did not fit better than a single compartment model based on AIC estimates. This indicated that the mineralizable nitrogen pool in the soils used could not be divided into multiple compartments in relation to its decomposability. This further implies that the pattern of nitrogen mineralization from residual manure in the manured plots could not be discriminated from that from the native soil organic nitrogen.

The nitrogen mineralization parameters obtained are shown in Table 2. The mineralization rate constants ranged from 0.0040 to 0.0081 (/day, 25°C). The apparent activation energy ($E_a$) ranged from 9,900 to 23,200 cal/mol. So far the temperature coefficient $Q_{10}$ had been used to describe the temperature dependency of the mineralization rate. However $Q_{10}$ did not remain constant in a wide range of temperatures, and changed with the temperature level tested. Therefore $E_a$ is considered to be a much better parameter regarding the temperature dependency of the nitrogen mineralization rate. The range of NMP was almost the same as that reported previously (*1, 2, 10, 13, 14, 16, 18, 19*).

The mineralization potential ($N_0$), which indicates the amount of potentially mineralizable nitrogen, ranged from 4.7 to 30.6 mg N/100 g dried soil. The proportion of $N_0$ to total N which ranged from 2.0 to 16.0% was higher in the soil with a low content in organic matter than in the soil rich in organic matter. Figure 1 which shows the relationship between $N_0$ and total nitrogen (TN) expressed on an area basis reveals two facts. Firstly, under the same cultural practices the amount of $N_0$ per area tended to be constant in spite of a marked difference in the soil nitrogen content. Secondly, each soil type showed a high correlation between $N_0$ and the total soil nitrogen

Table 2. Nitrogen mineralization parameters.

| Year | | Soil | Mineralization potential $N_0$ (mg N/100 g soil) | Rate constant $k$ ($\times 10^{-3}$/day, 25°C) | Apparent activation energy $E_a$ (cal/mol) |
|---|---|---|---|---|---|
| 1983 | 1. | Ishidoriya | 6.11±0.41 | 6.00±0.74 | 14,000± 650 |
| | 2. | Ishidoriya, manured | 15.00±1.01 | 8.12±1.17 | 9,900± 990 |
| | 3. | Matsukawa | 4.69±0.46 | 4.75±0.75 | 16,400± 740 |
| | 4. | Matsukawa, manured | 14.38±0.56 | 6.51±0.46 | 18,700± 550 |
| | 5. | Toshima | 10.85±0.58 | 7.82±0.91 | 12,000± 730 |
| | 6. | Toshima, manured | 25.58±2.61 | 4.03±0.59 | 12,100± 522 |
| | 7. | Kuriyagawa | 13.73±1.34 | 4.70±0.78 | 23,200±1,130 |
| | 8. | Kuriyagawa, manured | 30.58±1.92 | 6.25±0.70 | 17,600± 800 |
| 1984 | 9. | Ishidoriya | 8.46±0.46 | 6.81±0.86 | 13,100± 880 |
| | 10. | Matsukawa | 6.31±1.00 | 7.65±3.30 | 15,300±3,500 |
| | 11. | Toshima | 12.15±0.79 | 5.92±0.84 | 15,300± 890 |
| | 12. | Kuriyagawa | 16.46±1.45 | 4.38±0.70 | 21,000±1,080 |

The parameters were expressed with the standard error.

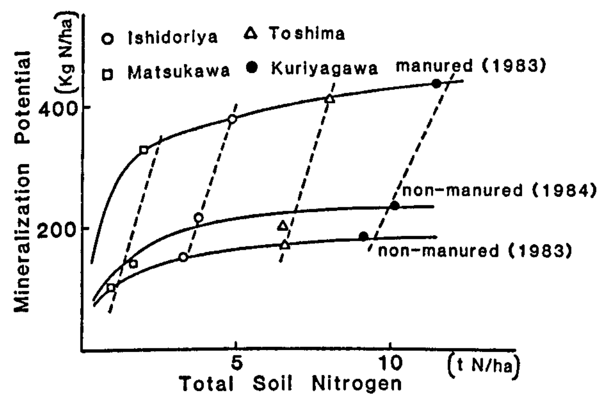


Fig. 1. Relationship between nitrogen mineralization potential ($N_0$) and total soil nitrogen content. Solid lines show the relationship for the group under the same cultural practices. Dot lines show the relationship among the same kinds of soils.

expressed by the following formula: $N_0 = A \times (\mathrm{TN} - B)$, where $A$ and $B$ are constants. This indicated that $B$ corresponded to the fraction of "recalcitrant" soil nitrogen (non-biodegradable nitrogen) and reflected the proper value for the soil, and that the slope of the regression line, $A$, corresponded to the proportion of $N_0$ to the "non-recalcitrant" soil nitrogen fraction, $(\mathrm{TN} - B)$, and did not differ significantly among the soils. The same relationship was observed for the readily decomposable nitrogen of the paddy soil *(21)*. These facts suggest that both the pool size of mineralizable soil nitrogen per area and its quality were mainly determined by soil management and the climate rather than by the soil properties.

*Estimation of soil nitrogen mineralization and uptake of soil nitrogen by corn*

In 1983 due to the cold weather which affected the soil temperature (Fig. 2), the growth of the corn plants was delayed and the yield was much lower than that in the other years. Nitrogen balance at harvest (Table 3) shows that in the non-manured plots, the recovered nitrogen, *i.e.* the sum of the amount of mineralized nitrogen taken up by the crop and the content of mineral nitrogen in the plow layer, was almost equivalent to the estimated amount of mineralized nitrogen based on NMP. In the manured plots, however, the estimated amount was greater than that of the recovered nitrogen.

In 1984 as the summer was hot and harvest good, the amount of nitrogen recovered from mineralized nitrogen almost coincided with the estimated amount of nitrogen in two Ando soils (soils No. 11 and No. 12), but in the other two soils (soils No. 9 and No. 10) it was significantly lower than the estimated amount (Table 3).

Figures 3 and 4 show that the pattern of soil nitrogen absorption by corn was different from that of estimated nitrogen mineralization. This findings may be interpreted as follows. In the earlier growing season as the amount of mineralized nitrogen exceeded the plant requirements, the mineralized nitrogen leached from the plow layer and accumulated in the layers beneath, from which the crop absorbed the mineralized nitrogen in the later part of the growing season. Since the subsoil of an Ando soil has a high water holding capacity, a large amount of nitrate can be accumulated and absorbed by the crop when roots elongate into this layer *(6)*.

The moisture conditions of soil affect the rate of nitrogen mineralization *(11, 15)*.

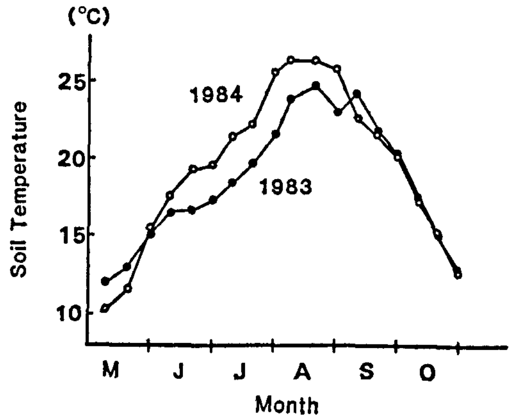


Fig. 2. Soil temperature during the growing season. Temperature was expressed as an average of 10 days.

Table 3. Growth of corn and nitrogen balance at harvest.

| Year | Soil | Total dry weight (t/ha) | N uptake by corn (kg N/ha) | | | Mineral N in plow layer (kg N/ha) | Recovered N (kg N/ha) | Mineralized N estimated from soil temperature (kg N/ha) |
|---|---|---|---|---|---|---|---|---|
| | | | Total | From fertilizer | From soil | | | |
| | | | A+B | A | B | C | B+C | |
| 1983 | 1. Ishidoriya | 1.23 | 134 | 66 | 68 | 12 | 80 | 74± 7 |
| | 2. Ishidoriya, manured | 1.47 | 169 | 36 | 132 | 19 | 151 | 226±22 |
| | 3. Matsukawa | 0.50 | 69 | 28 | 40 | 10 | 50 | 52± 6 |
| | 4. Matsukawa, manured | 1.41 | 163 | 43 | 120 | 10 | 130 | 159± 8 |
| | 5. Toshima | 0.85 | 107 | 29 | 78 | 5 | 83 | 103± 9 |
| | 6. Toshima, manured | 1.16 | 154 | 31 | 123 | 5 | 128 | 152±18 |
| | 7. Kuriyagawa | 1.31 | 126 | 44 | 82 | 4 | 86 | 85±10 |
| | 8. Kuriyagawa, manured | 1.46 | 170 | 43 | 127 | 8 | 135 | 204±18 |
| 1984 | 9. Ishidoriya | 2.19 | 180 | 73 | 107 | 8 | 115 | 145±15 |
| | 10. Matsukawa | 2.13 | 151 | 61 | 89 | 4 | 93 | 131±36 |
| | 11. Toshima | 2.08 | 174 | 57 | 118 | 5 | 123 | 124±14 |
| | 12. Kuriyagawa | 2.13 | 171 | 63 | 107 | 6 | 113 | 127±16 |

Corn was harvested on Sept. 13, 1983 and Sept. 25, 1984. The soil dry weight in plow layer (20 cm depth) was 250, 220, 160, and 140 kg/m$^2$ for the Ishidoriya, Matsukawa, Toshima, and Kuriyagawa soils, respectively.

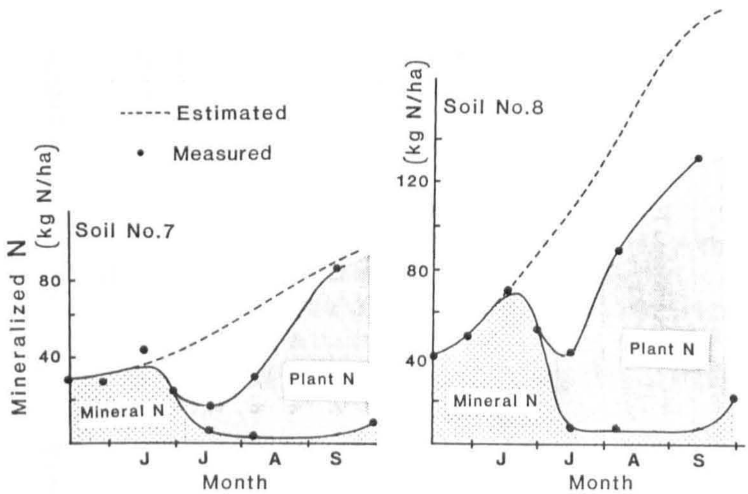


Fig. 3. Estimated nitrogen mineralization, soil nitrogen absorption by corn and mineral nitrogen in plow layer in 1983.

In 1983 the soil moisture was kept at a level approaching the field capacity during the growing season. Under such moisture conditions nitrogen mineralization may be mainly determined by the soil temperature. In contrast to 1983, less rain was observed from the end of June to the middle of August in 1984. The surface soil was fairly dried, so that the nitrogen mineralization in this season seemed to be suppressed, which may account for the discrepancy between the estimated and the measured values in soils No. 9 and No. 10 (Fig. 4). Since the two Ando soils showed a higher water holding capacity than the other soils, it is assumed that the suppression of nitrogen mineralization due to soil drying did not occur (Fig. 4).

*Efficiency of fertilizer nitrogen in relation to nitrogen mineralization*

The absorption efficiency of fertilizer nitrogen was determined by using $^{15}N$ labeled fertilizer (Table 3). In 1983 the values which ranged from 29 to 66% were generally lower than those reported (*12*), presumably due to the poor growth of corn in this year. In fact the absorption efficiency in 1984 was much higher than that in 1983. Figure 5 shows the uptake of nitrogen from soil and fertilizer in relation to the amount of mineralized nitrogen estimated from the soil temperature. The comparison between the estimated amount of mineralized nitrogen and the uptake of soil nitrogen first made it possible to estimate the absorption percentage of soil nitrogen by the crop. Although the values estimated were somewhat unreliable, the soil nitrogen absorption percentage ranged from 68 to 96% during the growing season inasmuch as the amount of mineralized nitrogen was less than 150 kg N/ha. A significant amount of fertilizer nitrogen was found to be absorbed even when the amount of soil nitrogen exceeded the plant requirements, which underlines the significance of basal application of nitrogen

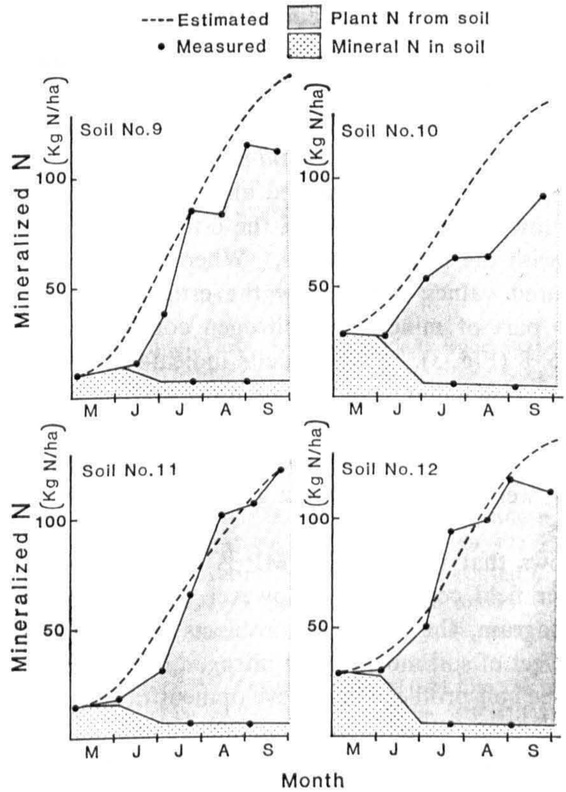


Fig. 4. Estimated nitrogen mineralization, soil nitrogen absorption by corn and mineral nitrogen in plow layer in 1984.

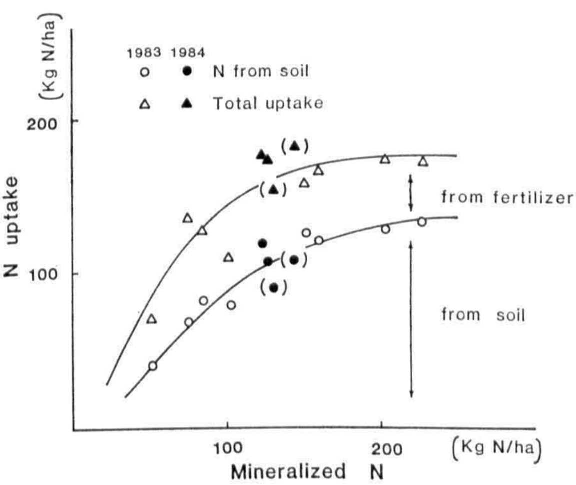


Fig. 5. Nitrogen absorption of corn in relation to mineralized soil nitrogen estimated from soil temperature. The data of soils No. 9 and No. 10 are indicated in the parentheses.

fertilizer in corn plants. Thus the use of the $^{15}N$ labeled fertilizer combined with the method of estimation of nitrogen mineralization provides valuable information for the sound management of soil fertility.

*Applicability of the present method under field conditions*

The relationship between the estimated amounts of mineralized nitrogen and the measured ones is shown in Fig. 6. When the estimated values were less than 130 kg N/ha, they agreed with the measured ones. When the estimated values exceeded this amount, the measured values were below the estimated ones. In these cases it is probable that only part of mineralized nitrogen could be recovered by the crop as observed in soil No. 8 (Fig. 3). These results indicate that the extent of soil nitrogen mineralization under field conditions can be estimated by the present method unless the soil is dry as in the case of soils No. 9 and No. 10, in 1984 (Fig. 4). YAMAMOTO *et al.* (*20*) who also evaluated the applicability of this method in paddy soils where soil drying never occurs, were able to observe a good agreement between the estimated and the measured values.

This study shows that the use of NMP is effective for estimating soil nitrogen mineralization under field conditions. However, for the application of this method to a soil testing program, the following problems should be taken into account for the model: 1) the effect of soil moisture on nitrogen mineralization, 2) the mobilization of nitrate through the soil profile, 3) the development of the root system. Although a model in which these factors were considered was reported (*22*), too many parameters were included. As the determination of the NMP parameters is laborious, a much simpler model and method should be developed for practical use. Furthermore en-

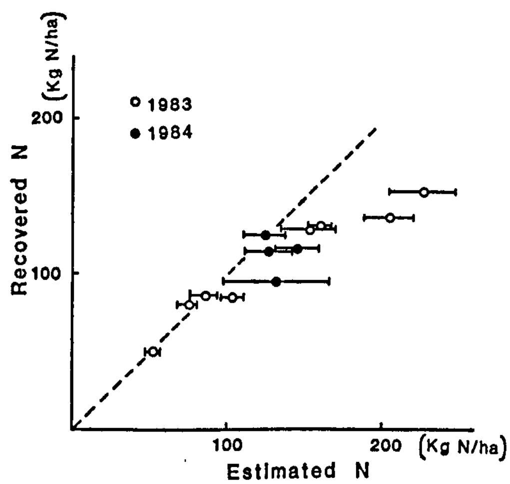


Fig. 6. Relationship between the estimated amount of mineralized nitrogen and the recovered one. The bar indicates the standard error of an estimate.

vironmental variables such as soil temperature and moisture should be estimated based on meteorological data which are currently available.

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