Effects of Controlled-Release Nitrogen Fertilizer Application on Nitrogen Uptake by a Leafy Vegetable (Brassica campestris L.), Nitrate Leaching and N₂O Emission

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Abstract  The application of nitrogen (N) fertilizer is an important cultivation option to enhance profitable production in general, and especially in the Southeast Asian countries or other tropical countries. In some cases, large amounts of N remain in soils after the crops are harvested, leading to the deterioration of the groundwater quality through nitrate leaching and of air quality through nitrous oxide (N₂O) emission. The purpose of the present study was to determine the effects of three types of controlled-release N fertilizers (CRFs) on: a) leafy vegetable growth, b) nitrate leaching from the surface (0-20cm) soil, and c) N₂O flux in the soil surface. Komatsuna (Brassica campestris L.) plants were grown in plastic containers filled with arable soil, and five treatments were applied as follows: application of CDU, UBF, UBM2 and urea fertilizers, and control (no N fertilizer). Three types of CRFs and urea were applied at the rate of 150 kg N ha⁻¹. The treatments with UBM2 and urea resulted in the highest values for the growth parameters and N uptake of Komatsuna plants. The amounts of total nitrate in the leachate were significantly higher in the UBM2 and UBF treatments than in the CDU and urea ones. The highest N₂O emission from soil was observed in the CDU treatment, followed by UBF, UBM2, urea and the control. The nitrogen use efficiency was highest in the treatments with UBM2 and urea.

Key Words: Komatsuna, groundwater pollution, global environment, nitrogen use efficiency

Introduction

Tropical regions or Southeast Asian countries are characterized by an equatorial monsoon climate with a wet and dry season. The prevailing soil types in the lowlands are alluvial soil and Latosol, while in the highlands, Andosol, Latosol and Regosol. In the highlands and lowlands of tropical regions or Southeast Asian countries, vegetable production is mainly carried out by comparatively small-scale farmers with strong nitrogen fertilizer dependence (Grubben, 1990). Nitrogen supply is a major factor for controlling the yield and quality of vegetables. In commercial field vegetable production, the application of nitrogen fertilizer is an important cultivation measure for profitable production. Often, large amounts of nitrogen remain in soil after the crops are harvested (Amkha et al., 2006). This nitrogen consists of residual soil mineral nitrogen and nitrogen present in crop residues. Both sources of nitrogen residues may exert harmful effects on the environment. They affect the groundwater quality through nitrate leaching and the global environment through nitrous oxide (N₂O) emission (Neeteson et al., 1999). Sustainable field vegetable production should be promoted with the reduction of the nitrogen input, which, however, may result in lower yields. Nitrogen fertilizer application for vegetable production must be developed under new fertilizer strategies (controlled-release fertilizer), by which the nitrogen supply is in synchrony with the dynamic nitrogen demand of the crop.

Controlled-release fertilizers have been used to save labor in farming systems where frequent applications of chemical fertilizers are required and to increase the nitrogen recovery by crops. Controlled release of urea and NH₄⁺-based fertilizers can be achieved by coating in various ways, chemical modifications and changes in the size of fertilizer granules. Controlled-release nitrogen fertilizer has many advantages over conventional fertilizer, including reduction in labor with a single basal application and higher nitrogen uptake efficiency by crops (Shoji et al., 1991; Shoji and Gandeza, 1992). It is also environment-friendly in terms of reduction of fertilizer N losses associated with leaching and denitrification (Ueno and Yamamuro, 1996).

In the present experiment, two kinds of controlled-release nitrogen fertilizers, CDU and UBER, were used. CDU is a commercially slow-release nitrogen fertilizer produced by combining urea and liquid...
aldehyde. CDU is considered to be only slightly soluble in water and therefore, relies on decomposition by soil microorganisms.

UBER is a new biodegradable and controlled-release nitrogen fertilizer made of CDU (2-oxo-4-methyl-6-ureidohexahydro-pyrimidine) with release-controlling additives. Therefore, the purpose of the present study was to determine the effect of different types of controlled-release nitrogen fertilizers and urea on a) leafy vegetable (Brassica campestris L.) growth, b) nitrate leaching from surface (0-20 cm) soil, and c) N₂O flux in surface soil.

**Materials and Methods**

The experiment was conducted in the Soil Science experimental field, Faculty of Horticulture, Chiba University, Matsudo, Japan during the period of April-June 2005. A plastic tank (30 cm length × 40 cm width × 30 cm height) was filled with arable soil (Fig. 1). The soil was classified as Andosol, and was characterized by a total C content of 20.9 g kg⁻¹ soil, total N content of 2.1 g kg⁻¹ soil, CEC of 22.4 cmol(+) kg⁻¹ soil, bulk density of 0.80 Mg m⁻³ and pH 5.9 (Sakamoto and Hodono, 2000). A leafy vegetable (seeds from Sakata Co., Ltd.), Komatsuna (Brassica campestris L.) was sown on cell trays. After 14 days, the seedlings were transplanted to plastic tanks containing the Andosol. The plants were arranged at a 20 cm spacing between two rows and at a spacing of 10 cm in the row. The treatments consisted of the application of different nitrogen fertilizer types: urea (Wako Company) and three types of controlled-release fertilizers (CDU, UBER-four (UBF) and UBER-micro2 (UBM2)) from Chisso Co., Ltd.. Nitrogen fertilizers were applied at a rate of 15 g N m⁻² (150 kg N ha⁻¹). Tanks without nitrogen fertilizer were also set up as control. All the treatments consisted of the application of basal fertilizers together with commercial fertilizers (0-13-13) at the rate of 10 g P-K m⁻² (100 kg P₂O₅-K₂O ha⁻¹). According to the product information (Chisso fertilizer Co., Ltd.), CDU, UBF and UBM2 released 80% of nitrogen at 25 °C at 90-140, 30-60 and 20-30 days after fertilizer application, respectively. The experimental layout consisted of a completely randomized design with 5 treatments and 3 replications.

The expected growth period was 40 days after transplanting to the plastic tanks. Plant height (cm) was measured at 10-day intervals after transplanting until harvest (40 days after transplanting (DAT)). The leaf color was also quantified using a Chlorophyll meter (SPAD) (Minolta Co. Ltd., SPAD-502). At harvest, the fresh weight of the plants (g plant⁻¹) was measured. All the plant (g plant⁻¹) materials were dried at 80 °C for 5-7 days in a forced air oven, dry weight was measured, then the samples were ground and sieved (0.5 mm). The nitrogen content of the plant samples was measured using a C/N analyzer (MT 700 with an autosampler MTA600, Yanaco, Japan). Finally, the following parameters were determined: (1) Yield (kg m⁻²); (2) Nitrogen uptake (g m⁻²); (3) N agronomic efficiency (NAE, kg kg⁻¹), as the ratio of (yield with Napplied-yield of Ncontrol) to applied N; (4) N use efficiency (NUE, kg kg⁻¹), as the ratio of yield to total nitrogen uptake; (5) N apparent recovery fraction (NARF, %), as the ratio of (total N uptake with Nappplied ~ N uptake of Ncontrol) to applied N, and (6) Plant growth rates (cm day⁻¹) indicated as the increase in plant height per day.

Soil samples (0-20 cm) were taken using a core sampler (Ø5 cm) from the tank at the mid-season cropping (20 DAT) and at harvest time (40 DAT). Soil samples were sieved and stored at 4-5 °C until analysis. Soil samples were extracted with 1.0 M KCl for the analyses of nitrate and ammonium contents. The contents of nitrate and ammonium in the soil extract were determined by the hydrazine reduction (Hayashi et al., 1997) and colorimetric nitropusside methods (Anderson et al., 1989), respectively.

The amount of nitrate leached was measured in the water coming out from the tube attached to the bottom of the tank. The total amount of leachate depended on the rainfall. The leachate was collected at 15 and 25 days after transplanting.

A closed-chamber method was used to determine the fluxes of N₂O in each plastic tank. The system consisted of a white plastic chamber with a cross-sectional area of 216 cm² (16 cm × 13.5 cm) and height of 10 cm. Each chamber was placed in the center of a tank, as shown in Figure 1. Gas samples were taken at certain time intervals (1, 2, 4, 7, 11, 16, 22, 29 and 37
days after fertilizer application). Each time, four samples of air from the chamber were pulled into 30 ml syringes at 0, 10, 20 and 30 minutes after closure, injected into pre-evacuated vials fitted with butyl rubber stoppers and taken to the laboratory for analysis. During gas sampling, the air temperature inside the chamber was also measured with a digital Thermo Recorder (model TR-71S). N₂O concentration was analyzed using GC-ECD (Shimadzu, GC 14B) equipped with an electron capture detector at 280°C. The separating column was packed with Porapak Q and the carrier gas consisted of 5% methane in Argon. The N₂O flux \((\text{mg N}_2\text{O-N m}^{-2}\text{ h}^{-1})\) was calculated from the temporal increase of the gas concentration inside the chamber per unit time as follows:

\[
F = k \frac{V}{A} \frac{dC}{dt} \left(\frac{273}{(273+T)}\right)
\]

where \(k\) is a constant for conversion from volume to weight \((\text{N}_2\text{O} = 1.250)\), \(V\) and \(A\) are the volume of effective space and area of the bottom of the chamber, respectively, \(T\) is the air temperature inside the chamber (°C), and \(dC/dt\) is the increase in the gas concentration inside the chamber over the closure period. Total N₂O emission \((\text{mg N}_2\text{O-N m}^{-2}\text{crop}^{-1})\) was calculated by integrating the amount of emitted N₂O with the duration of the measurement.

Total N₂O emission = \(\int F \, dt\)

where \(F\) is the N₂O flux and \(t\) is the time. The nitrogen losses as N₂O gas or emission factor (EF %) were expressed as the ratio of the (total amount of N₂O emitted from fertilized samples – total amount of N₂O emitted from unfertilized samples) to the total amount of nitrogen fertilizer applied into soil (Tsuruta et al., 1997).

Statistical analyses were performed using the statistical package “SPSS 11”. Difference treatments and data variance were determined by analyses of variance (ANOVA). Mean comparison among the treatments was performed using Tukey test at the 5% significance level.

**Results**

Although the value of the plant height was higher with fertilizer application than without (control), the plant height in all the fertilizer treatments was not significantly different at 10, 20 and 30 DAT. At 40 DAT, the value of the plant height was highest in the urea treatment and it was significantly different from that in the CDU and UBF treatments but not from that in the UBM2 treatment (Table 1). SPAD readings in all the fertilizer treatments were significantly higher than those of the control at 40 DAT, while at 30 DAT, only the SPAD readings from the UBF and UBM2 treatments were different from those of the control. The yield and N uptake in all the fertilizer treatments were significantly higher than those in the control at harvest time (40DAT) (Table 2). Among the fertilizer treatments, yield and N uptake were significantly higher for urea and UBM2 than for CDU and UBF. The mean values of NAE (plant ability to increase the yield in response to N fertilizer levels) for urea and UBM2 were not significantly different, but they were significantly higher than those for CDU and UBF (Table 3). NUE of urea was significantly higher than that of the controlled-release N fertilizers. Among the controlled-release fertilizers, UBM2 exhibited the highest NUE. NARF, which indicates the ability of the plant to increase N uptake in response to N applied, was substantially higher for urea and UBM2 than for CDU and UBF. All the treatments led to an increasing growth rate from 10-30 DAT. The growth rate continued to increase after 30 DAT in the control but it decreased in the fertilizer treatments (Fig. 2). Furthermore, significant differences in the growth rate were found between the control (without fertilizer) and N fertilizer

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Effect of nitrogen fertilizer types on plant height and leaf color at 10-40 days after transplanting (DAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>Plant height (cm)</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Urea</td>
<td>5.63 a</td>
</tr>
<tr>
<td>CDU</td>
<td>5.88 a</td>
</tr>
<tr>
<td>UBF</td>
<td>5.88 a</td>
</tr>
<tr>
<td>UBM2</td>
<td>5.88 a</td>
</tr>
<tr>
<td>Control</td>
<td>2.68 b</td>
</tr>
<tr>
<td>F-test</td>
<td>*</td>
</tr>
</tbody>
</table>

* Means in the same column followed by the same letter are not different (p>0.05), according to Tukey test (n=3). Absence of letters denotes nonsignificant difference; **Nonsignificant.
Table 2  Effect of nitrogen fertilizer types on dry weight, yield and N uptake in Komatsuna at harvest time (40 DAT)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry weight (g plant⁻¹)</th>
<th>Yield (kg FW m⁻²)</th>
<th>N uptake (g m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>7.67 a</td>
<td>4.32 a</td>
<td>10.4 a</td>
</tr>
<tr>
<td>CDU</td>
<td>5.01 b</td>
<td>2.88 b</td>
<td>9.8 b</td>
</tr>
<tr>
<td>UBF</td>
<td>5.50 b</td>
<td>3.15 b</td>
<td>9.9 b</td>
</tr>
<tr>
<td>UBM2</td>
<td>7.19 a</td>
<td>4.24 a</td>
<td>11.1 a</td>
</tr>
<tr>
<td>Control</td>
<td>0.35 c</td>
<td>0.49 c</td>
<td>0.4 c</td>
</tr>
</tbody>
</table>

F-test * * *

1 Means in the same column followed by the same letter are not different (p<0.05), according to Tukey test (n=3).

Fig. 2  Effect of nitrogen fertilizer types on plant growth rate indicated by the increase in plant height per day at 0 - 40 days after transplanting. Means followed by the same letter are not significantly different at each day (Tukey P<0.05).

At 20 DAT, the nitrate content in soil was significantly higher in all the fertilizer treatments, compared with the control. Moreover, the soil nitrate content was the highest in the UBM2 treatment, followed by UBF among the fertilizer treatments. At harvest time, the amount of nitrate that remained in soil was much higher in the CDU and UBF treatments than in the urea and UBM2 treatments where the soil nitrate contents were the same as those of the control (Fig 3). Ammonium content in soil was not significantly different among all the treatments, including the control at 20 DAT and at harvest time (40 DAT).

The amounts of nitrate in the leachate were significantly higher in the UBM2 and urea treatments than in the CDU and UBF ones at 15 DAT (Fig. 4), while at 25 DAT, the amounts of nitrate leached were significantly higher in the UBM2 and UBF treatments than in the CDU and urea ones. Then, the total amounts of nitrate leached were highest in UBM2, followed by UBF, urea, CDU and the control, in this order.

The highest N₂O flux was observed at 2 days after urea application (Fig. 5). Among the controlled-release fertilizers, the peak value of the N₂O flux was highest in CDU at 22 DAF, followed by UBF at 16 DAF and UBM2 at 11 DAF. However, the total N₂O emission

Table 3  Effect of nitrogen fertilizer types on N agronomic efficiency (NAE), N use efficiency (NUE) and N apparent recovery fraction (NARF) in Komatsuna at harvest time (40 DAT)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NAE (kg kg⁻¹)</td>
</tr>
<tr>
<td>Urea</td>
<td>255.3 a</td>
</tr>
<tr>
<td>CDU</td>
<td>159.3 b</td>
</tr>
<tr>
<td>UBF</td>
<td>177.3 b</td>
</tr>
<tr>
<td>UBM2</td>
<td>250.0 a</td>
</tr>
</tbody>
</table>

F-test * * *

1 Means in the same column followed by the same letter are not different (p<0.05), according to Tukey test (n=3).
Fig. 4 Effect of nitrogen fertilizer types on nitrate leaching at 15 and 25 days after transplanting. Means followed by the same letter are not significantly different at each day (Tukey P<0.05). Values in parenthesis indicate the total amount of nitrate leached during the 25-day period of plant growth.

Discussion

The plant growth rate and yield of komatsuna were significantly higher in the urea and UBM2 treatments than in the CDU and UBF treatments (Fig. 2 and Table 2). Urea and UBM2 increased the growth rate and yield by more than 8 times, compared with the control. This could be explained by the N-release patterns of the different fertilizers applied. Urea is initially hydrolyzed to ammonium within 1-2 hours after application by the enzyme urease from soil microorganisms. Then ammonium is nitrified to nitrate by nitrifying bacteria (Zhou et al., 2006). Nitrogen from UBM2, UBF and CDU is also released as ammonium but longer periods are required for the release of most of ammonium from these fertilizers. Nitrogen from CDU and UBF is slowly released at 90-160 and 30-60 days after fertilizer application, respectively, while UBM2 releases nitrogen at 20-30 days after application. The plant growth rate with UBM2 at 20-30 DAT was comparable with that of urea because most of nitrogen is released during this period. However, the growth rates and yields with CDU and UBF were also higher than those of the control at 20-30 DAT, suggesting that some of the nitrogen may have been utilized by the plant. Moreover, the amounts of nitrate and ammonium in soil at 20 DAT were higher in the CDU and UBF treatments than in the control one (Fig. 3), suggesting that some of the nitrogen became available within 20 days after application. SPAD meter readings have been used to detect N deficiency in rice and wheat. In wheat, 40 and 50 SPAD units measured from leaves suggested the existence of lower and higher levels for nitrogen supply (Vidal 1999), i.e. a SPAD reading of less than 40 indicated N deficiency. However, in the present experiment, no differences in the SPAD readings were observed among all the treatments, including the control at 10-20DAT (Table 1). The fertilized treatments showed differences in SPAD readings from the control only at 30-40DAT. Greater differences were observed among the treatments in terms of plant height, which also suggests the existence of differences in the total leaf area. SPAD meter readings are related to the leaf chlorophyll and N contents per unit leaf area (Ladha et al., 1998). Therefore, since the SPAD reading or amount of leaf N per unit area did not vary, the plant height would be a better indicator of total plant N uptake from the fertilizers applied. At 40 DAT, there was a significant correlation between the plant height

Table 4 Effect of nitrogen fertilizer types on total amount of N\textsubscript{2}O emitted and emission factor (EF)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Total N\textsubscript{2}O emitted \textsuperscript{a} (mg N\textsubscript{2}O-N m\textsuperscript{-2} crop\textsuperscript{-1})</th>
<th>EF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>61.8 c\textsuperscript{b}</td>
<td>0.2 b</td>
</tr>
<tr>
<td>CDU</td>
<td>186.0 a</td>
<td>0.6 a</td>
</tr>
<tr>
<td>UBF</td>
<td>145.8 b</td>
<td>0.5 a</td>
</tr>
<tr>
<td>UBM2</td>
<td>64.8 c</td>
<td>0.2 b</td>
</tr>
<tr>
<td>Control</td>
<td>10.2 d</td>
<td>-</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Means in the same column followed by the same letter are not different (p>0.05), according to Tukey test (n=3).

\textsuperscript{b} F-test.
and the actual N uptake measurements ($R^2 = 0.975$).

Ammonium and nitrate contents in soil varied with the different types of N fertilizers applied and their N release patterns. Ammonium and nitrate from urea are readily available in soil and could be subjected to losses from ammonia volatilization, denitrification or nitrate leaching, if not immediately taken up by the plants. The nitrate N content of soil was much higher in the UBM2 treatment than in the urea treatment at 20 DAT (Fig. 3), although the plant height and SPAD readings which indicate the N uptake at 20 DAT were not different between the two treatments. This could be due to denitrification losses from urea early in the growth cycle (Fig. 5). However, the growth rates as measured from the changes in the plant height at 20-30 DAT (Fig. 2) and the total amount of plant N uptake at 40 DAT were also similar in the UBM2 and urea treatments. This, on the other hand, could be explained by the higher amount of nitrate leached from UBM2 at 25 DAT, compared with that from urea (Fig. 4). It appears that the amount of nitrate leached at 25 DAT was related to the amount of nitrate in soil at 20 DAT. In the UBF treatment which led to a higher nitrate N content in soil than that in the urea and CDU treatments at 20 DAT (Fig. 3), a higher amount of nitrate was leached at 25 DAT (Fig. 4). Davies and Sylvester-Bradley (1995) reported that the annual amount of NO$_3$-N leached in agricultural land in Britain increased by 36 kg ha$^{-1}$ over a 50-year period and that one-third was derived from residual nitrate. In another study, it was shown that 68% of NO$_3$-N accumulation occurred outside in the root zone and that one-third was derived from residual nitrate. In some studies, it was reported that the amount of N leached into the groundwater in a vegetable exceeded over 200 kg N ha$^{-1}$ (Prunty and Greenland, 1997; Stites and Kraft, 2001; Romos et al., 2002; Kraft and Stites, 2003) and even 500 kg ha$^{-1}$ in some cases (Zhu et al., 2005). In addition to environmental factors such as climatic conditions and soil properties, nitrate leaching is also strongly affected by management practices, such as fertilizer application, irrigation, rainfall and planting patterns. Differences in the N uptake capacity of crops, fertilizer management and irrigation in different cropping systems may lead to various patterns of nitrate accumulation in the soil profile.

Urea exhibited a peak of N$_2$O flux at 2 days after application, which quickly decreased after 4 days. Zhou et al. (2006) also found that when urea was added to soil, it was enzymatically hydrolyzed to NH$_4^+$ during its transport through the soil profile; and the hydrolysis to NH$_4^+$ occurred within several hours after application. Therefore, changes in the distribution of NH$_4^+$ and NO$_3^-$ in the soil profile after fertilizer application reflect not only the movement of soil N, but also the transformation of urea-N fertilizer. On the other hand, the controlled-release fertilizers exhibited broad peaks of N$_2$O flux with a longer duration of N$_2$O emission. Consequently, the highest total N$_2$O emission was observed from CDU which was slowest in releasing NH$_4^+$-N and NO$_3^-$-N. Since CDU requires at least 90 days to release NH$_4^+$-N and NO$_3^-$-N, nitrate remained in soil even at the harvest day of the crop, while the plant growth rate was the lowest at 30-40 days after transplanting. Since plants could not absorb a large amount of nitrate-N from soil, the total N$_2$O emission was high in the CDU treatment. Among the slow-release N fertilizers, UBM2 gave the lowest N$_2$O emission, similar in amount to that of urea although N$_2$O emission from urea was observed earlier than that from UBM2 (Fig. 5). The formation of N$_2$O is mostly biogenic and occurs simultaneously through both denitrification and nitrification processes, with the dominant process depending on the availability and type of substrates and on the soil water regimes (Khalil et al., 2002; Khalil and Baggs, 2005). Nitrogen losses, as N$_2$O gas emission, in the present experiment ranged from 0.2-0.6% of the total amount of fertilizer nitrogen (Table 4). Tsuruta et al. (1997) reported that N losses as N$_2$O from a Japanese garden amounted to 5.82% of nitrogen applied with manure compost. Webb et al. (2000) reported annual N$_2$O losses of 0.5-2.7% from an arable field in the UK, while Kaiser et al. reported values of N$_2$O losses ranging from 0.7 to 4.1%. The N$_2$O emission from agricultural land may range from 0.03 to 2.7% (Eichner, 1990) and can even amount to 5.8% (Dobbie et al., 1999) of added nitrogen. The accumulation of N$_2$O in soil and emission to the atmosphere were differently influenced by the amount of N fertilizer applied, agricultural practices, soil properties and climatic conditions. However, if nitrogen uptake by plant cannot be increased, part of the nitrogen will be released slowly to the environment sooner or later. In order to reduce the impact on the environment, it is important to select the right type of controlled-release fertilizer whose nitrogen release rate matches the nitrogen demand of the plant.

In the present study, it was shown that UBM2 may be appropriate for rapidly growing plants, such as komatsuna, since the N release pattern of UBM2 is in
synchrony with the nitrogen requirement of this plant. In terms of N use efficiency, NAE and NARF of UBM2 were comparable with that of urea, although NUE of urea was higher than that of UBM2. Among the slow-release N fertilizers, UBM2 gave the lowest \( N_2O \) emission similar in amount to that of urea, although \( N_2O \) emission from urea was observed earlier than that from UBM2. On the other hand, UBF and CDU were found to be less appropriate for growing komatsuna. However, the present study should be extended to consider the N use efficiency of these controlled-release N fertilizers for two or more crops. The optimum nitrogen fertilizer rate for leafy vegetable production must be defined as the highest rate of nitrogen use efficiency, because of the higher utilization of available nitrogen by the crop and the reduction of the losses to the environment. The application of UBF and CDU for growing two or more crops may allow a more efficient use of N than that of a single crop system with mineral N fertilizers through the exploitation of residual fertility in crop rotation, which may also reduce the contamination of surface water and the losses to the environment.

Acknowledgments

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References


緩効性窒素肥料がコマツナの窒素吸収量，硝酸態窒素の溶脱,
N₂O の放出に与える影響

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要約 窒素（N）肥料の施用は東南アジアをはじめ様々な国において収穫後の食糧生産を増加させるために重要である。収穫後に土壌中に多くの窒素が残存している場合，硝酸態窒素による地下水汚染や亜酸化窒素（N₂O）による大気汚染の原因となる。この研究の目的は3 種類の緩効性 N 肥料がa）葉物野菜の生長，b）硝酸態窒素の表土（0-20cm）からの溶脱，c）土壌表面からの N₂O 放出にそれぞれ与える影響を調査することである。プラスチック製のコンテナに細土壌を充填し，コマツナ（Brassica campestris L.）を栽培し，以下の5つの試験区条件—CDU, UBF, UBM2, 尿素，対照区（無 N 肥料区)—をコンテナごとに与えた。3 種類の緩効性 N 肥料と尿素はそれぞれ150 kg N ha⁻¹の割合で施肥した。コマツナの生長測定項目と N 吸収量は UBM2 と尿素区で最も高かった。溶脱した硝酸態窒素量は UBM2 と UBF 区においてCDUと尿素区よりも有意に高かった。土壌からの N₂O 放出量は CDU 区において最も高く，続いて UBF, UBM2, 尿素，対照区の順であった。N 利用効率は UBM2 と尿素区において最も高かった。

キーワード：地下水汚染，地球環境，窒素利用効率

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