# Fate of $^{15}$N-urea blended with composted pig manure for Chinese cabbage

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**Abstract**

To utilize composts more efficiently, combining composts with fertilizer to meet crop requirements is an appealing alternative. A pot experiment was conducted to study the effect of application rate of composted pig manure (CPM) blended with chemical fertilizer on the availability, immobilization, and loss of fertilizer-N. Chinese cabbage [*Brassica campestris* (L.) Samjin] plants were cultivated for 30 and 60 days. $^{15}$N-Labeled urea (5.24 $^{15}$N atom%) was added to soil at 450 kg N ha$^{-1}$, and unlabeled CPM (0.37 $^{15}$N atom%) was added at 0, 200, 400, and 600 kg N ha$^{-1}$. The amount of plant-N derived from urea was not affected by CPM application at rate of 200 kg N ha$^{-1}$. However, CPM application at 400 and 600 kg N ha$^{-1}$ significantly ($P < 0.05$) increased plant assimilation of N from urea irrespective of sampling time, probably because of physicochemical changes in the soil properties allowing urea-N to be assimilated more efficiently. Immobilization of urea-N linearly increased with increasing rate of CPM application at the both growth periods, resulting from increased microbial activities using organic C in the CPM. However, the percentages of immobilized N from urea decreased between the 30- and 60-day growth periods, indicating net remineralization of previously immobilized urea-N. With increasing rate of CPM, total recovery of urea-N (as percentage of added N) by Chinese cabbage and soil increased from 71.5 to 95.6% and from 67.0 to 88.2% after the 30- and 60-days of growth, respectively. These results suggest that increasing rate of compost application increases plant uptake of chemical fertilizer-N blended with compost and enhances immobilization of fertilizer-N, which leads to decrease in loss of fertilizer-N.

**Keywords:** urea, compost, uptake efficiency, mixed application, immobilization

## Introduction

Optimal use of compost as a source of N for crop production requires information on the availability of N in the compost. Paul and Beauchamp (1993) observed that the N recovery by corn decreased in the order of urea, liquid manure, and solid or composted manure because of stabilization of manure-N during the composting process through microbial immobilization and humification.

Because of low nutrient content and low plant-availability of compost as compared to chemical fertilizer, the compost application rate necessary to satisfy the complete N or P requirement of a crop is large. Although compost application has beneficial effects on crop production (Eghball and Power, 1999), excessive application increases soil levels of P and other ions, leading to water and soil contamination (Sharpley *et al*., 1984). For that reason, combining low amendment rates of composts with sufficient fertilizer to meet crop requirement is considered as an appealing alternative (Sikora and Enkiri, 2001).

Combined application of the inorganic fertilizers with the organics can lead to an increase in the availability of nutrients and crop yield (Patra *et al*., 2000). However, the effects of compost on the availability and fate of chemical fertilizer-N when applied together are not yet well-understood (Sikora and Enkiri, 2001). Recently, Choi *et al*. (2001) suggested that combined application of urea with compost increased microbial immobilization of urea-N and this resulted in lower loss of urea-N as compared to treatment without compost. However, crop availability and microbial immobilization of chemical fertilizer-N blended with compost may differ depending on the application rate of compost. The objective of this study, therefore, was to determine the effect of application rates of compost on crop uptake, immobilization, and loss of urea-N applied to a Chinese cabbage.

## Materials and Methods

### Compost and urea

$^{15}$N-Labeled urea and unlabeled composted pig manure (CPM) were used as N sources. CPM was made by mixing pig manure and sawdust using a pilot scale enclosed reactor (Choi *et al*., 1996). CPM was crushed to pass through a 2-mm sieve. Nitrogen contents of CPM were 2.06% for total-N, 0.114% for $NH_4^+$-N, 0.038% for $NO_3^-$-N, and 1.91% for organic N. The $^{15}$N-labeled urea (5.24 $^{15}$N atom %) was prepared by diluting 98 $^{15}$N atom % urea (Isotec, USA) using unlabeled urea.

### Pot experiment

A pot experiment with Chinese cabbage was conducted using sandy loam soil (Typic Dystrudepts) in a greenhouse between September and November 2000. Contents of organic carbon and total nitrogen of soil were 2.02 and 0.13%, respectively. Pots (30 cm in diameter × 30 cm in depth) with closed bottoms were used to prevent N loss through leaching. To allow aeration, a PVC tube (2.5 cm in diameter × 40 cm in length) was installed in each pot. $^{15}$N-Labeled urea (5.24 $^{15}$N atom %) at 450 kg N ha$^{-1}$ with CPM at 0, 200, 400, and 600 kg N ha$^{-1}$ (UC0, UC1, UC2, and UC3 treatments, respectively) were used for comparison through 30- and 60-day analyses. Urea solution and compost, together with the fused phosphate and KCl at a rate of 43.7 kg P ha$^{-1}$ and 124.5 kg K ha$^{-1}$, respectively, were mixed thoroughly with 10 kg soil, and the mixture was packed into each pot. All treatments were triplicated. One seedling of Chinese cabbage was transplanted to each pot. Mean N content of the seedling was 15.6 mg (n=10, T-N=6.4%, Dry weight= 243.5 mg), which was subtracted from the final dry weight and N content of crop at harvest. During growth, soil water content was measured through time domain reflectometry measurements (Trace, Soil moisture Equipment Corp., USA) and adjusted daily to 0.25 m$^3$m$^{-3}$ (35 kPa) by watering from the surface manually.

**Sampling and analyses**

Aboveground parts of Chinese cabbage were carefully collected at 30 and 60 days after transplanting. Samples were dried at 60°C and weighed to determine the dry weight. Soil was sampled from the thoroughly mixed soil section and air-dried. Total N content and $^{15}N$ atom % of crop and soil samples were determined using a stable isotope ratio mass spectrometer (IsoPrime-EA, Micromass, UK) linked with an elemental analyzer. Nitrogen content and $^{15}N$ atom % of 2 M KCl non-extractable N (immobilized N) were determined using the mass spectrometer after removing inorganic N from the soil sample through the KCl extraction (Choi *et al*., 2001).

**Calculations and statistical analysis**

Total amount of N derived from $^{15}N$-labeled urea (NDFU) was calculated for crop and soil samples by the isotope method as follows (Choi *et al*., 2001):

$$NDFU = (T \times A_S)/A_F$$

where, T is total weight of N in the urea-amended sample, $A_S$ is atom % excess $^{15}N$ in the urea-amended sample, and $A_F$ is atom % excess $^{15}N$ in applied urea. Regression method (Westerman and Kurtz, 1974) was applied to determine the total amount of N derived from compost (NDFC) in crop. The total amount of plant-N derived from soil (NDFS) was determined by subtracting (NDFU+NDFC) from total plant-N. The NDFU of 2 M KCl extractable soil-N was calculated as the difference between NDFU of total soil-N and NDFU of 2 M KCl non-extractable N. The recoveries of N by crop and soil were expressed as percentages of N applied to each pot.

Using Generalized Linear Models procedures (SAS Institute, 1989), data were analyzed using the least square difference test after one-way ANOVA for a completely randomized design with three replications to compare the significance among the treatments.

## Results and Discussion

**Effect of CPM application on yield and N uptake of Chinese cabbage**

Application of CPM significantly ($P < 0.05$) increased the dry matter yield of Chinese cabbage at both harvest times. In the presence of CPM, however, incremental yield increases with increasing application rate of CPM was not great (Table 1). Organic matter amendments to soils result in yield increases primarily from improvement of soil moisture holding capacity or other physical factors (Tester, 1990). In addition, both minerals and trace metals in composts are beneficial to crop growth.

The total amounts of N taken up by Chinese cabbage also increased significantly ($P < 0.05$) with increasing application rate of CPM regardless of the sampling time (Table 1). Application of CPM at a rate of 2,000 mg N $pot^{-1}$ (UC1) did not increase NDFU significantly ($P < 0.05$) over treatment without compost (UC0). However, CPM application at rates of 4000 (UC2) and 6,000 (UC3) mg N $pot^{-1}$ resulted in significant increase in NDFU at the both sampling times. In accordance with NDFU data, treatments receiving CPM over 4,000 mg N $pot^{-1}$ showed significant ($P < 0.05$) increase in the uptake efficiency of urea-N at the both sampling times, i.e. the efficiencies increased from 10.4% for UC0 to 10.8% for UC3 and from 17.7% for UC0 to 24.1% for UC3 after 30 and 60 days of growth, respectively. This result could be attributed to the positive growth responses from CPM applied in combination with chemical fertilizers, since physicochemical changes in the soil properties induced by compost application could allow the chemical fertilizer to be utilized more efficiently (Kropisz and Kalinska, 1983). In general, when compost application rate is greater than a critical level, improvement of soil physical properties is apparent, e.g. Tester (1990) reported that 50,000 kg compost $ha^{-1}$ is the critical application rate. Therefore, the critical level for the compost used in the present study seemed between 9,710 and 19,420 kg compost $ha^{-1}$.

**Table 1** Dry matter yields (DMY) and uptake of N.

| Trt† | DMY ($g\ pot^{-1}$) | | Uptake of N ($mg\ N\ pot^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 30-day | | | | 60-day | | | |
| | 30-day | 60-day | NDFU ‡ | NDFC ¶ | NDFS § | SUM | NDFU | NDFC | NDFS | SUM |
| UC0 | 17.7 | 60.9 | 467 | 0 | 383 | 850 | 680 | 0 | 569 | 1249 |
| UC1 | 20.0 | 97.0 | 461 | 176 | 359 | 996 | 716 | 366 | 499 | 1581 |
| UC2 | 22.0 | 103.1 | 484 | 352 | 334 | 1170 | 779 | 732 | 372 | 1883 |
| UC3 | 24.1 | 109.2 | 484 | 528 | 366 | 1378 | 847 | 1098 | 424 | 2369 |
| LSD (*P*=0.05) | 1.9 | 5.5 | 10 | 45 | 56 | 53 | 55 | 78 | 62 | 70 |

† Urea at 4500 mg N $pot^{-1}$ with CPM at 0, 2000, 4000, and 6000 mg N $pot^{-1}$ (UC0, UC1, UC2, and UC3 treatments, respectively.

‡ Calculated using isotope method.

¶ Calculated using regression method.

§ Calculated using difference method.

NDFU, NDFU, and NDFS denote the amount of N derived from urea, compost, and soil, respectively.

**Effect of CPM application on microbial immobilization of urea-$^{15}N$**

The amount of 2 M KCl non-extractable N from urea significantly ($P < 0.05$) increased with increasing application rate of CPM (Table 2). Soils treated with organic amendments generally have larger microbial populations and higher activity than those treated with inorganic fertilizers (Marcote *et al*., 2001). Between the 30- and 60-day growth periods, the amount of immobilized urea-N decreased (Table 2), indicating remineralization of N. This result could be attributed to decrease in the amount of microbial-available organic C. Since compost is generally heterogeneous, consisting of more than two components decomposing at different rates (Choi *et al*., 2001), the amount of easily decomposable organic C is likely to decrease with time.

Since added nitrogen interaction (ANI) is strongly influenced by the rate at which applied N is immobilized, ANI is directly proportional to the rate of N immobilization. ANI due to pool substitution often results in higher uptake of the indigenous soil N by plants in the fertilized soil than in the unfertilized control (Kuzyakov *et al*., 2000). However, ANI may be negative or absent with different experimental conditions (Kuzyakov *et al*., 2000). The NDFS for UC0, UC1, UC2, and UC3 were 383, 359, 334, and 366 mg N $pot^{-1}$ after the 30-day growth period and 569, 499, 372, and 424 mg N $pot^{-1}$ after the 60-day growth period, respectively (Table 1). These results suggest that a positive ANI was not apparent across the whole range of CPM applications in spite of the increased immobilization of urea-N with increasing rates of CPM as shown in Table 2.

**Table 2** Total recovery of $^{15}$N-labeled urea-N.

| Trt† | As % of added 4,500 mg urea-N pot$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30-day | | | | 60-day | | | |
| | Org-N‡ | Inorg-N¶ | Plant-N | Loss§ | Org-N | Inorg-N | Plant-N | Loss |
| UC0 | 56.6 | 4.5 | 10.4 | 28.5 | 51.1 | 0.8 | 15.1 | 33.0 |
| UC1 | 66.2 | 5.2 | 10.2 | 18.4 | 60.6 | 1.0 | 15.9 | 22.5 |
| UC2 | 73.0 | 5.6 | 10.8 | 10.6 | 64.3 | 0.5 | 17.3 | 17.9 |
| UC3 | 78.7 | 6.1 | 10.8 | 4.4 | 68.8 | 0.6 | 18.8 | 11.8 |
| LSD (*P*=0.05) | 3.7 | 0.1 | 0.2 | 2.5 | 1.4 | 0.0 | 1.2 | 2.1 |

† Details of treatment are described in Table 1
‡ 2 M KCl non-extractable N
¶ 2 M KCl extractable N
§ Unaccounted portion

**Effect of CPM application on loss of urea-$^{15}$N**

Soil and Chinese cabbage retained 71.5% of the applied urea-N for UC0 after the 30-day growth period (Table 2). CPM application significantly ($P < 0.05$) increased the recovery to 81.5, 89.4, and 95.6% for UC1, UC2, and UC3, respectively. Therefore, the unaccounted portions significantly ($P < 0.05$) decreased with increasing rate of CPM application. After 60-days of growth, although the unaccounted portions significantly ($P < 0.05$) increased as compared with the 30-day growth period, compost application still resulted in significantly ($P < 0.05$) higher recovery of the applied urea-N (Table 2). This result was because of the enhanced microbial immobilization of urea-N. Because the bottoms of the pots used in this study were closed, the unrecovered urea-N could be attributed to disappearance through denitrification or volatilization (Limaux *et al.*, 1999). However, the contribution of $NH_3$ volatilization to urea-N loss seemed less significant than that of denitrification because the soil pH was acidic (5.1) and urea was homogeneously mixed with the soil (Fenn and Miyamoto, 1981). Denitrification rates in aerobic soil tended to increase through the application of fertilizer N and adequate watering (Weitz *et al.*, 2001). Since organic carbon additions may decrease nitrification rates but increase the total microbial activity (Strauss and Lamberti, 2000), the enhanced microbial assimilation of urea-N using available-C in CPM could be assumed to allow lower production of $NO_3^-$, which is the denitrification substrate, upon the CPM treatment than without the CPM (Choi *et al.*, 2001).

**Uptake of compost-N**

After 30- and 60-days of growth, the uptake efficiencies of compost (the gradient of the regression of crop N uptake on compost-N applied) were 8.8 and 18.3%, respectively (Figure 1). These values were similar to the results reported through several studies (Beauchamp, 1986; Paul and Beauchamp, 1993). The uptake efficiencies suggest that CPM was heterogeneous, consisting of easily decomposable organic N and more resistant organic N (Beauchamp, 1986). After the decomposition of relatively unstable components was completed, the amount of available N for corn was to be quite low. Initially, 7.35% of total N in the CPM was present in an inorganic N form, which was equivalent to 147, 294, and 441 mg N pot$^{-1}$ for UC1, UC2, and UC3 treatments, respectively. Thus, assuming that total inorganic compost-N was available to the Chinese cabbage, the amounts of CPM-N mineralized and assimilated by Chinese cabbage (NDFC minus inorganic N in CPM) during the 30-day growth period were 29 mg N for UC1, 58 mg N for UC2, and 87 mg N for UC3. This amount was equivalent to 1.6% of the content of organic N (1,853 for UC1, 3,706 for UC2, and 5,559 mg N for UC3) of the CPM. For the 60-day growth period, 11.8% of the organic N fraction of the CPM was mineralized and assimilated by the Chinese cabbage. Eghball (2000) reported that approximately 10% of organic N was mineralized from composted manures. The low N availability of compost is because of the stabilization of manure-N during the composting process through microbial immobilization and humification (Paul and Beauchamp, 1993). Often, however, compost amendments mineralize N in the second and third years after application (Sullivan *et al*., 1998).

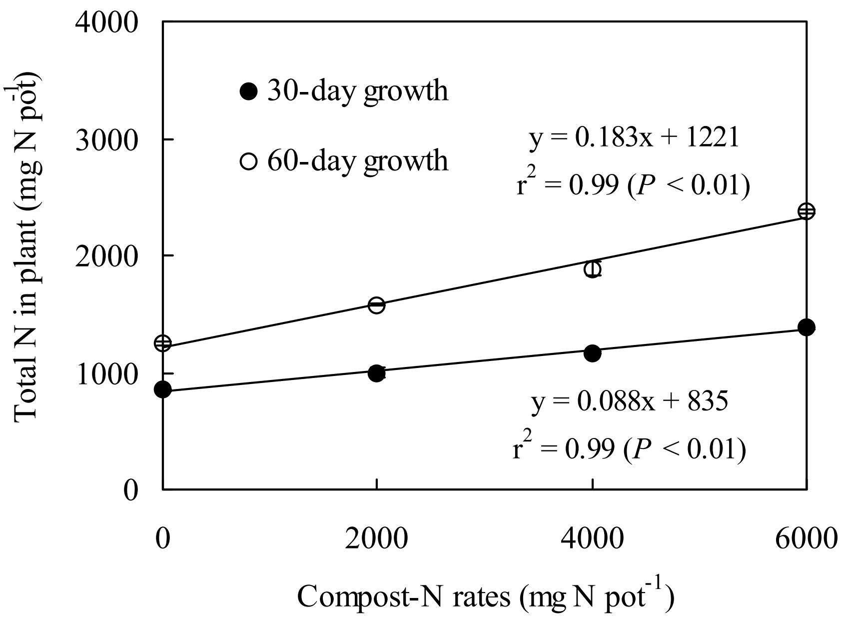


**Figure 1** Effect of increasing additions of CPM on the uptake of total-N by Chinese cabbage at 30-days (closed circle) and 60-days (open circle) of growth. Values are the mean of the triplicates. The gradient is the average fraction of CMP-N recovered by Chinese cabbage. Bars show standard deviation of the mean.

## Conclusions

Application of CPM over 9,710 kg compost ha$^{-1}$ increased plant uptake of urea-N due to the positive growth responses from CPM applied in combination with urea. Immobilization of the applied urea-N increased in proportion to application rates of CPM, mainly because of stimulated microbial activities using organic C in CPM. Microbial immobilization led to the higher retention of the applied urea-N and thus resulted in less loss of urea-N compared to the treatment without compost. The second crop may assimilate the retained N derived from urea.

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