Acidulocompost, a food waste compost with thermophilic lactic acid fermentation: its effects on potato production and weed growth

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ABSTRACT
Acidulocomposting recycles food wastes by means of thermophilic lactic acid fermentation. This process can decrease ammonia volatilization and odor emission during processing and produce compost with high nitrogen (N) content. To compare the yield of potatoes (Solanum tuberosum L. ‘Dansyakuimo’) and the suppression of weeds with acidulocompost (AC) and those with conventional composts and inorganic fertilizer (IF), we conducted field experiments in Miyagi Prefecture, northeastern Japan. Potatoes were cultivated in 2008 and 2009 in an Andosol field treated with AC, conventional food waste compost (FWC), poultry manure compost (PMC), cattle manure compost (CMC), IF, or no fertilizer (NF). AC, but not the other treatments, delayed the emergence of potatoes, and suppressed the emergence of weeds, but it did not inhibit potato growth during the late growth stage or yield. Potato N uptake and tuber yield with AC were significantly higher than those with NF and similar to those with FWC, PMC, and IF. The N uptake efficiencies (ratio of difference between N uptake in the treatment and the control to added N) for AC (10.4–12.7% in 2008 and 2009) were similar to those for FWC and PMC (10.2–13.1%), higher than those for CMC (–1.3 to 6.3%), but significantly lower than those for IF (30.2–42.3%). Our findings indicate that AC has an N supply capacity similar to those of FWC and PMC and additionally suppresses the emergence and growth of weeds.

The annual production of biological waste in Japan reached approximately 280 Mt in 2000 (Kida et al., 2004). Included in this amount are the food wastes generated by homes, restaurants, and food industries, which amounted to 22 Mt Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF, 2006). Because food wastes are generally rich in nitrogen (N), phosphorus (P), potassium (K), and other plant nutrients, food waste composts (FWC) are considered to be useful for agricultural production as fertilizers or soil conditioners. However, only 20% of food wastes were recovered for use as fertilizers or animal feed (MAFF, 2006), in part because several problems associated with composting systems have not been solved, including the emission of offensive odors and the labor-intensive procedures required to maintain the composting process. Thus, in order to increase the food waste recovery rate, composting systems must be improved.

Acidulocomposting, a relatively new composting system invented by Nishino et al. (2003), offers a practical method to recycle food wastes. The acidulocomposting facility has devices for heating, mixing, and ventilating and can automatically keep temperatures between 50 and 70 °C and maintain acidic conditions (pH 3.5–6.5) via the production of lactic acid by thermophilic lactic acid bacteria (Asano et al., 2010; Hemmi et al., 2004) for more than 2 yr, with very low odor emissions and little labor needed during the process (Nishino et al., 2003). The acidulocompost (AC) produced is acidic (typically pH 4.5–5.5) and has a caramel-like and weakly burnt smell (Nishino et al., 2003).

Conventional composting processes, which decompose organic matter aerobically, generally proceed under slightly alkaline conditions (pH 7.5–9), which promote ammonia volatilization. Gaseous N losses during the composting of livestock manures and sewage sludge under alkaline conditions are potentially high, with reported values of approximately 46–77% (Witter & Lopez-Real, 1988) and more than 60% (Martins & Dewes, 1992) of the total N in the raw materials. Because acidulocomposting proceeds under acidic conditions, N losses through ammonia volatilization are very low (Asano et al., 2010). Therefore, the acidulocomposting method may decrease ammonia volatilization and air pollution and increase the compost’s N content. Because of these advantages, the system has

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Site and soil

In 2008 and 2009, we conducted field experiments at the Field Science Center of the Graduate School of Agricultural Science, Tohoku University, Osaki, Miyagi, in northeastern Japan (38°44′ N, 140°15′ E). The field used for the 2009 experiment was adjacent to the one used in 2008. The soil type was Melanic Aluandic Andosol (Ito & Saigusa, 1996) according to WRB (IUSS Working Group, 2006). The soil characteristics in the top 15 cm in 2008 and 2009, respectively, were pH (H2O) of 6.38 and 6.40, total C content of 97.5 and 99.1 g kg−1, and total N content of 6.06 and 5.94 g kg−1. The available phosphate content (Truog method; Truog, 1930) in 2008 was 0.59 g kg−1.

The data of temperature and precipitation during the experiment period were collected from Kawatabi weather station adjacent to the experimental field.

Composts

We used four types of compost in the experiments. AC was produced by acidulocomposting food waste generated in Ibaraki Prefecture, Japan. Conventional FWC was produced by aerobic digestion by a company in Miyagi Prefecture, Japan. Poultry manure compost (PMC) was produced by aerobic digestion at a layer farm in Miyagi Prefecture. Cattle manure compost (CMC) was produced at the Field Science Center, Tohoku University, where dairy cattle manure was composted at an open-type high-rate composting facility.

Chemical properties of the composts are listed in Table 1. Total C and N contents of compost samples were measured using an NC analyzer (Sumigraph NC-80; Sumika Chemical Analysis Co., Osaka, Japan). Available N in PMC was shown to been implemented at approximately 60 sites, including schools, hospitals, aquariums, and food industries, in Japan and Indonesia (Star Engineering Co., Ltd., 2016). However, the effects of AC application on crop production have not been well evaluated.

Weed control is important for achieving sustainable agriculture with high yields. Weeds in uplands are usually controlled by cultural methods (intertillage, mulching) and herbicides. Although herbicides are effective, if their application rates can be reduced without loss of crop yield, agricultural costs can be reduced. Several researchers have investigated the inhibition of plant germination and growth by compounds present in some organic wastes and composts, such as fatty and phenolic acids (Cayuela et al., 2008; Fiorentino et al., 2003; Ishidori et al., 2005; Marambe et al., 1993; Nagaoka et al., 1996). In our previous preliminary AC application (to a depth of 0–15 cm) experiments, the growth of some weeds was suppressed in a potato field (unpublished data). AC surface application (to a depth of 0–5 cm) like mulching may enhance the effect of weed control. Moreover, a 1-yr field experiment revealed that application of AC derived from food waste increased potato yields (Tatenai et al., 2006). However, the effects of AC application position (application to a depth of 0–15 cm and 0–5 cm) on potato growth and yields, N uptake of potato, and weed germination and growth need to be clarified in detail for improving AC utilization methods in potato cultivation.

In this study, we investigated the effects of AC application on the production of and N uptake by potato and weed growth in field experiments in the Tohoku region of Japan. We compared the effects of AC application with those of three other composts and urea, and evaluated the effects of AC application position (incorporation to a depth of 0–15 cm and 0–5 cm).

Materials and methods

Composts

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| Composts              | pH (H2O) | ECa (dS m−1) | Total C (g kg−1) | Total N (g kg−1) | Available Nb (g kg−1) | Total P2O5 (g kg−1) | Total K2O (g kg−1) | C/N |
|-----------------------|----------|--------------|------------------|------------------|-----------------------|---------------------|-------------------|-----|
| Acidulocompost        | 4.9      | 4.9          | 514              | 43.7             | 0.6 (0.3)c            | 7.8                 | 9.0               | 11.8|
| Food waste compost    | 8.3      | 5.2          | 264              | 30.5             | 5.1 0.3              | 25.3                | 7.6               | 8.7 |
| Poultry manure compost| 8.5      | 7.3          | 263              | 40.2             | 14.8 (8.4)           | 54.7                | 39.6              | 6.5 |
| Cattle manure compost | 9.2      | 5.8          | 393              | 19.3             | 0.5 (0)              | 16.6                | 38.1              | 20.4|

aEC, electrical conductivity.

bAvailable N in composts = amount of uric acid N + amount of inorganic N. Uric acid N was extracted using phosphate acid buffer solution (pH 7), and inorganic N was extracted using 1 M HCl.

cValues in parentheses are contents of uric acid N in composts.
have a strong relationship with N uptake by plants (Hidaka et al., 2006). It can be used for determining the rate of compost application to soil. Available N is evaluated as the sum of uric acid N and inorganic N. Uric acid N was extracted with phosphoric acid buffer solution (Murakami et al., 2007), and inorganic N (including ammonium N, nitrate N, and ammonium magnesium phosphate) was extracted with 1 M HCl (Tanahashi et al., 2010). Total P and total K contents were measured by the dry combustion method (Yokota et al., 2003): after combustion, the concentration of P in the extract was determined by the colorimetric method of Murphy and Riley (1962), and the concentration of K was determined by atomic absorption spectrometry.

To estimate the pattern of N mineralization from the composts, we evaluated cumulative mineralized N (expressed as a percentage of the initial added N from the composts) by means of aerobic incubation of a mixture of fresh soil and compost (Tanahashi & Yano, 2004). The quantity of the compost to mix with the soil was determined from the total N in the compost so that the total N in dry compost equaled 30 mg per 100 g dry soil. The mixture was incubated at 30 °C for 8 wk, with two replicates in 2008 and three in 2009, and samples were collected and measured at 0, 1, 4, and 8 wk after the start of incubation. The incubation with FWC was not conducted in 2009. The moisture content was kept at 60% of the maximum water-holding capacity. The N mineralization rate was calculated at each sampling time:

\[
\text{N mineralization rate} = \left( \frac{\text{mineralized N in soil mixed with compost} - \text{mineralized N in soil without compost}}{\text{total compost N added}} \right) \times 100 \%
\]

The mineral N (ammonium N plus nitrate N) was extracted from samples using the Bremner method, and the N concentration was determined by the steam distillation method (Bremner & Keeney, 1965).

### Treatments

We used seven fertilization treatments: AC15 (incorporation of AC to a depth of 0–15 cm), AC5 (incorporation of AC to a depth of 0–5 cm), FWC, PMC, CMC, inorganic fertilizer (IF), and no N fertilizer (NF). In the FWC, PMC, and CMC treatments, compost was incorporated into the top 15 cm. The mineral N (ammonium N plus nitrate N) was extracted from samples using the Bremner method, and the N concentration was determined by the steam distillation method (Bremner & Keeney, 1965).

### Cultivation

In each treatment plot, we installed a bottomless wooden frame (0.9 m² = 1.2 m × 0.75 m; 0.2 m in height) to a depth of 15 cm. On 22 April 2008 and 20 April 2009, we incorporated composts and IF into the soil, and planted four seed tuber pieces (30 to 50 g per piece) of potato (Solanum tuberosum L. ‘Dansyakuimo’) into the soil to a depth of 10 cm in each frame. The plots (frames) were arranged in a randomized complete block design with four replicates per treatment. Potatoes were also planted around the experimental plots as a border. The planting density was 4.4 plants m⁻² (0.3 m × 0.75 m spacing). Potatoes were thinned to two seedlings per seed tuber (eight seedlings per plot) after emergence. No weeding was conducted during early potato growth (0 to 50 days after planting; DAP) in both years, and manual weeding and ridging was conducted at 51 DAP.

Potatoes were cultivated from 22 April to 30 July 2008 (99 d) and from 20 April to 14 July 2009 (85 d). In 2009, potatoes were harvested early to prevent the spread of bacterial soft rot.

### Table 2. The application rates of the composts and inorganic fertilizer.

| Treatmenta | Compost and IF application method | Dry matter N | P₂O₅ N | K₂O N | IF (g m⁻²) | P₂O₅ N | K₂O N |
|---|---|---|---|---|---|---|---|
| AC₁₅ | Incorporationb | 581 | 27.8 | 4.9 | 4.3 | 0 | 13.1 |
| AC₅ | Surface applicationc | 581 | 27.8 | 4.9 | 4.3 | 0 | 13.1 |
| FWC | Incorporation | 878 | 27.8 | 22.6 | 7.4 | 0 | 0 |
| PMC | Incorporation | 650 | 27.8 | 36.1 | 26.1 | 0 | 0 |
| CMC | Incorporation | 1,186 | 27.8 | 22.9 | 50.5 | 0 | 0 |
| IF | Incorporation | 0 | 0 | 0 | 10.0 | 18.0 |
| NF | 0 | 0 | 0 | 0 | 0 | 0 |

aAC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer.
bIncorporation with compost and IF to a depth of 0–15 cm.
cIncorporation with compost to a depth of 0–5 cm and with IF to a depth of 0–15 cm.
Weeds
Changes of the weed cover ratio (percentage of the soil surface covered by weed leaves) and the number of monocot and dicot weeds were determined in quadrats (0.3 m × 0.3 m) during early crop growth (0–51 DAP) in 2009. The quadrats for measuring weed growth were set up on the soil surface that potato plants were not planted in each plot. We photographed the quadrats with a digital camera and calculated the weed cover ratio with version 1.44q of the ImageJ software (http://rsb.info.nih.gov/ij; Abdourhamane et al., 2011). The aboveground parts of the weeds were collected at 51 DAP and identified to species level; the weeds were then oven-dried at 70 °C to calculate the dry weight per unit area in 2008 and 2009.

Apparent N uptake efficiency
The apparent N uptake efficiency (ANUE) by potatoes was calculated as the ratio of N uptake to applied N:

\[
\text{ANUE} (%) = \left( \frac{\text{total N uptake in compost or IF treatment} - \text{total N uptake in NF treatment}}{\text{amount of N applied with compost or IF}} \right) \times 100\% \quad (2).
\]

Statistical analysis
The differences among the means were analyzed by the one way ANOVA and the Tukey–Kramer test in KyPlot software (KyensLab Inc., Tokyo, Japan). A P value of <0.05 was considered to be significant.

Results
Temperature and rainfall
Figure 1 shows the mean daily air temperature and monthly rainfall during the experiments. The mean temperatures in May (15.1 °C) and June (18.1 °C) in 2009 were higher than those in May (13.2 °C) and June (17.6 °C) in 2008. Rainfall was higher in July 2009 (5.1 mm day⁻¹) than in July 2008 (2.7 mm day⁻¹). Thus, it was hotter and more humid during 2009.

Characteristics of food waste AC
AC was acidic (pH 4.9 in 2008, 4.2 in 2009), but the other composts were slightly alkaline (pH 8.3 to 9.2 in 2008, 8.0 to 9.1 in 2009; Table 1). The total C and N contents of AC were generally higher than those of the other composts, and total P₂O₅ and K₂O were lower than those in PMC and CMC. The total N content was lowest in CMC.

Figure 2 shows the cumulative mineralization of N from composts during incubation. The patterns of N from AC, PMC, and CMC in 2009 were similar to those...
Soil pH (H₂O) at 18 DAP in 2008

The pH (H₂O) of soil (a depth of 0–5 cm) was the lowest in IF (5.64). The values in the other treatments ranged from 5.68 to 5.76. Moreover, the pH (H₂O) of soil (a depth of 5–15 cm) was also lower in IF (5.64) than in the other treatment (ranged from 5.77 to 5.91). Influence of AC application on soil pH (H₂O) was not observed.

Emergence, growth, and yield of potatoes

In 2008, the rate of potato emergence reached 50% in FMC, PMC, and IF at 17 DAP, in CMC and NF at 18 DAP, in AC₅ at 19 DAP, and in AC₁₅ at 20 DAP (Figure 3A). In 2009, the rate of potato emergence reached 50% in FMC, PMC, and IF at 17 DAP, in CMC and NF at 18 DAP, in AC₅ at 19 DAP, and in AC₁₅ at 20 DAP (Figure 3A).
the plant heights in AC15 and AC5 were the same as those in FWC, PMC, and IF and higher than in CMC and NF. At the later growth stage, plant heights in AC15 and AC5 were higher than those in CMC and NF in both years.

In 2008, potato tuber yield was higher in PMC and IF, and lower in CMC and NF. Total tuber yield in AC15 and AC5 was significantly higher than in NF in 2008, and there were no significant differences in yield among AC15, AC5, FWC, PMC, and IF (Figure 4). Marketable tuber yield in AC15 and AC5 showed no significant differences from other treatments, but values were lower than those of PMC and IF. Potato tuber yields in 2009 showed similar trends in 2008. In 2009, total tuber yield in AC15 and AC5 was significantly higher than in NF and CMC. There were no significant differences in yield among AC15, AC5, FWC, PMC, and IF in 2009. Marketable tuber yield in AC15 and AC5 was significantly higher than that in CMC and NF.

There were no significant differences in tuber yield between AC15 and AC5. Thus, the AC application method (deep versus surface incorporation) did not affect potato yield.

**N uptake by potatoes**

The trends in N uptake by potatoes (Table 3) were similar to the yield trends. Total N uptake was higher in IF, lower in CMC and NF in 2008 and 2009. Total N uptake was significantly higher in AC15 and AC5 than in NF in 2008 and 2009 and significantly higher than in CMC in 2008. Otherwise, there were no differences from other treatments. The ANUE was 10.8% in 2008 and 12.7% in 2009 for AC15 and 10.4 and 12.3% for AC5. These values were not significantly different from those for FWC and PMC (10.2–13.1%) and CMC (–1.3–6.3%). The ANUE was significantly higher in IF (30.2–42.3%) than in the compost treatments. There were no significant differences in N uptake and ANUE between AC15 and AC5. Thus, the AC application method (deep versus surface incorporation) did not appear to affect potato N uptake.

A significant relationship between the potato N uptake and marketable fresh yield was identified in both 2008 and 2009 (Figure 5).

**Number of weeds, dry weight, and N uptake by weeds**

Weed cover was lower in AC15 and AC5 than in the other treatments until 51 DAP in 2009 (Figure 6A-1). This was also true of the number of dicot weeds (Figure 6C-1) but not of the number of monocot weeds (Figure 6B-1). In particular, the number of dicot weeds that emerged between 0 and 34 DAP was lower in AC15 and AC5 than in other treatments, and significant differences between AC treatments and IF
were observed (Figure 6C-2). The numbers that emerged between 35 and 51 DAP did not show significant differences among treatments. In addition, there was less of an increase in weed cover in AC₁₅ and AC₅ than in the other treatments both during 0–34 DAP and 35–51 DAP (Figure 6A-2). There were significant differences between IF and AC₁₅ or AC₅ during 0–34 DAP and between IF and AC₅ during 35–51 DAP.

Species and numbers of monocot and dicot weeds at 51 DAP in 2008 and 2009 are shown in Figure 7. In 2008, the main weed species were the grasses Digitaria ciliaris (Retz.) Koeler, Echinochloa crus-galli (L.) P. Beauv., and Setaria faberi Herrm., and the dicots Polygonum blumei Meisn., Persicaria nepalensis (Meisn.) H. Gross, and Oenothera biennis L. In 2009 (in the adjacent field), the main weed species were E. crus-galli and the dicots P. blumei, O. biennis, and Stellaria media (L.) Villars. The grass weed species with the largest population in 2008 (D. ciliaris) differed from that in 2009 (E. crus-galli). Likewise, the dicot weed species with the largest population in 2008 (P. nepalensis) differed from that in 2009 (S. media). The total number of monocot weeds at 51 DAP was 800–2,900 plants m⁻² in 2008 and 170–270 plants m⁻² in 2009. The total number of dicot weeds at 51 DAP was 220–2,200 plants m⁻² in 2008 and 90–310 plants m⁻² in 2009. Thus, the total number of weeds was much higher in 2008.

### Table 3. N uptake and apparent N uptake efficiency (ANUE) by potatoes in 2008 and 2009.

| Treatmenta | N uptake (g m⁻²) | ANUE (%) |
|------------|------------------|----------|
|            | Aboveground | Tubers | Total |                  |
| 2008       |              |        |       |                  |
| AC₁₅       | 1.11 ab     | 6.89 a  | 8.00 a | 10.8 b           |
| AC₅        | 1.30 a      | 6.57 ab | 7.87 a | 10.4 b           |
| FWC        | 0.95 ab     | 6.87 a  | 7.82 ab| 10.2 b           |
| PMC        | 1.27 ab     | 6.56 ab | 7.83 ab| 10.2 b           |
| CMC        | 0.74 b      | 3.96 b  | 4.70 c | −1.3 b           |
| IF         | 1.00 ab     | 7.07 a  | 8.07 a | 30.2 a           |
| NF         | 0.76 ab     | 4.29 ab | 5.05 bc| −         |
| 2009       |              |        |       |                  |
| AC₁₅       | 1.52 ab     | 7.48 ab | 9.00 a | 12.7 b           |
| AC₅        | 1.53 ab     | 7.36 ab | 8.89 a | 12.3 b           |
| FWC        | 1.40 ab     | 7.35 ab | 8.75 a | 11.8 b           |
| PMC        | 1.78 a      | 7.32 ab | 9.09 a | 13.1 b           |
| CMC        | 1.28 ab     | 5.94 ab | 7.22 a | 6.3 b            |
| IF         | 1.45 ab     | 8.24 a  | 9.69 a | 42.3 a           |
| NF         | 1.12 b      | 4.35 b  | 5.46 b | −                 |

Within each year, values of the same parameter followed by the same letter are not significantly different (Tukey–Kramer test, \( p < .05, n = 4 \)). *AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC₁₅, AC incorporation in the top 15 cm; AC₅, AC incorporation in the top 5 cm.

**Figure 5.** Relationship between potato (aboveground plus tuber) N uptake and marketable tuber fresh yield in 2008 and 2009. \( r \) denotes Pearson correlation coefficients, *\( p < .05 \), **\( p < .01 \). AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC₁₅, AC incorporation in the top 15 cm; AC₅, AC incorporation in the top 5 cm.
The aboveground dry weight of weeds at 51 DAP was significantly lower in AC15 and AC5 than in FWC and IF in 2008, and then in FWC and PMC in 2009 (Figure 8). The aboveground dry weights in FWC and PMC were similar to that in IF in 2008 and 2009, and the weights in CMC and NF were significantly lower than that in IF in 2008.

Total N uptake by dicot weeds was lower in AC15 and AC5 than in the other treatments, and significantly less than in PMC (Table 4). Total N uptake by all weeds was higher in FWC, PMC, and IF (1788–2589 mg m⁻²) than in the other treatments (340–925 mg m⁻²).

Total N uptake by all weeds was significantly lower in AC5 than in AC15 (Table 4). Moreover, the number of weeds (Figure 7) and weed aboveground dry weight (Figure 8) were lower in AC5 than in AC15. Thus, the AC application method (deep versus surface incorporation) affected weed growth.

The total number of monocot weeds at 51 DAP was significantly lower in AC15 and AC5 than in FWC and IF in 2008, but no significant differences among treatments were observed in 2009 (Figure 7). In contrast, the total number of dicot weeds was lower in AC15 and AC5 than in the other treatments in both years, with a significant difference between AC5 and FWC, PMC, or IF in both years. The differences among treatments in the total number of dicot weeds showed similar trends in 2008 and 2009.

In 2008, the number of E. crus-galli plants was significantly lower in AC15 and AC5 than in IF (Figure 7). The number of P. blumei in 2008 was significantly lower in AC5 than in IF. The number of O. biennis in 2009 was significantly lower in AC15 and AC5 than in IF. However, there were no significant differences in the main monocot and dicot weed species between IF and PMC, CMC, or NF.

The aboveground dry weight of weeds at 51 DAP was significantly lower in AC15 and AC5 than in FWC and IF in 2008, and then in FWC and PMC in 2009 (Figure 8). The aboveground dry weights in FWC and PMC were similar to that in IF in 2008 and 2009, and the weights in CMC and NF were significantly lower than that in IF in 2008.
can cause problems for crops, such as N deficiency (Harada et al., 1993; Mathur et al., 1993; Umemoto et al., 2012). In contrast, organic matter in CMC (with higher CN ratio compared to AC) may be not decomposed rapidly just after application to soil.

Our incubation test results suggest that N immobilization occurs in the AC treatment field, but that this immobilization is temporary, because net N mineralization occurred within 4 to 8 wks. The cumulative N mineralization rate during the 8-wk incubation was higher in the AC treatment than in CMC, similar to that in FWC, and lower than in PMC. At 1 wk after incorporation, N mineralized from soil with PMC was highest among the four composts, because uric acid N content (which is easily mineralized) in PMC was high (Table 1), and this N may be decomposed quickly. This result shows that the N in PMC is readily available, as reported previously (Ushio et al., 2000, 2004).

**Discussion**

**Characteristics of AC used**

The AC used in this study was acidic and had a higher N content than the other composts (Table 1). This may be the result of a reduction in N loss during acidulocomposting under acidic conditions, as reported by Asano et al. (2010). The C content was also higher in AC than in the other composts. Moreover, AC showed N immobilization at 1 wk after incorporation into the soil, whereas the other composts did not (Figure 2). These findings indicate that the decomposition rate of organic matter during acidulocomposting was low, and that the AC contains a large amount of easily decomposable organic matter, as suggested by Heinai et al. (2009). The N immobilization may have been caused by initially rapid decomposition of easily decomposable organic matter in the AC. The application of such compost
other treatments in both years, and potato plant height at 31 DAP in 2009 was also significantly lower in AC15 than in PMC and IF (Figure 3). These results show potato growth was inhibited during the early growth stage by AC application, perhaps because (1) soil mineral N content was low due to N immobilization, caused by initially rapid decomposition of easily decomposable organic matter in AC, or (2) germination-inhibiting compounds were present or generated in the soil mixed with AC. However, plant height at 80 DAP and yield were not lower in the AC treatments than in CMC and NF (Figures 3 and 4). This suggests that more N was mineralized from AC at the later growth stage than from CMC and NF, as shown by the incubation test, in which AC released mineralized N at 4–8 wk (Figure 2). The potatoes emerged later in AC15 than in AC5 in both 2008 and 2009 (Figure 3). The reason for this was not clear, but it is one of the possible reasons that the content of germination-inhibiting compounds at the point of potato germination may be higher in AC15 than in AC5. Potato tuber yields in both AC treatments were significantly higher than that in NF, similar to those in FWC and PMC, and higher than those in CMC in both years (Figure 4). These results suggest positive effects of AC application on potato yield.

Little is known about the rate of plant N uptake from AC. We used non-isotopic methods to estimate the N derived from complex organic inputs of compost and assessed the difference in uptake using ANUE, but it will be necessary to evaluate the N uptake efficiency directly by using 15N-labeled organic matter. The N uptake efficiencies of potatoes based on the 15N method amounted to 31–72% of applied ammonium nitrate (Tran & Giroux, 1991). Potato ANUE amounted to 16% for CMC (Nakatsu & Tamura, 2009) and 29–70% for ammonium nitrate (Errebhi et al., 1998; Li et al., 2003). In the present study, potato ANUE ranged from –0.3 to 6.3% of the N applied in CMC, 10.2 to 13.1% of that applied in compost (AC, FWC, PMC), and 30.2 to 42.3% of the urea in IF (similar to the previously reported values) (Table 3). These findings show that the N supply capacity of AC was higher than that of CMC, similar to those of FWC and PMC, and lower than that of IF.

**Effects of AC application on growth and tuber yield of potatoes**

Tatenai et al. (2006) reported that soil pH (H2O) was decreased by AC application, but in the present study, AC application did not decrease the soil pH (H2O) at 18 DAP in 2008. The acidic characteristic of AC did not influence the soil acidity and may not affect potato growth. However, the potatoes emerged later in AC15 and AC5 than in the other treatments in both years, and potato plant height at 31 DAP in 2009 was also significantly lower in AC15 than in PMC and IF (Figure 3). These results show potato growth was inhibited during the early growth stage by AC application, perhaps because (1) soil mineral N content was low due to N immobilization, caused by initially rapid decomposition of easily decomposable organic matter in AC, or (2) germination-inhibiting compounds were present or generated in the soil mixed with AC. However, plant height at 80 DAP and yield were not lower in the AC treatments than in CMC and NF (Figures 3 and 4). This suggests that more N was mineralized from AC at the later growth stage than from CMC and NF, as shown by the incubation test, in which AC released mineralized N at 4–8 wk (Figure 2). The potatoes emerged later in AC15 than in AC5 in both 2008 and 2009 (Figure 3). The reason for this was not clear, but it is one of the possible reasons that the content of germination-inhibiting compounds at the point of potato germination may be higher in AC15 than in AC5.

Potato tuber yields in both AC treatments were significantly higher than that in NF, similar to those in FWC and PMC, and higher than those in CMC in both years (Figure 4). These results suggest positive effects of AC application on potato yield.

Little is known about the rate of plant N uptake from AC. We used non-isotopic methods to estimate the N derived from complex organic inputs of compost and assessed the difference in uptake using ANUE, but it will be necessary to evaluate the N uptake efficiency directly by using 15N-labeled organic matter. The N uptake efficiencies of potatoes based on the 15N method amounted to 31–72% of applied ammonium nitrate (Tran & Giroux, 1991). Potato ANUE amounted to 16% for CMC (Nakatsu & Tamura, 2009) and 29–70% for ammonium nitrate (Errebhi et al., 1998; Li et al., 2003). In the present study, potato ANUE ranged from –0.3 to 6.3% of the N applied in CMC, 10.2 to 13.1% of that applied in compost (AC, FWC, PMC), and 30.2 to 42.3% of the urea in IF (similar to the previously reported values) (Table 3). These findings show that the N supply capacity of AC was higher than that of CMC, similar to those of FWC and PMC, and lower than that of IF.

**Table 4. N uptake by weeds in 2009.**

| Treatment   | Monocotyledon | Dicotyledon | Total  |
|-------------|---------------|-------------|--------|
| AC15        | 170           | 255 bc      | 424 b  |
| AC5         | 141           | 199 c       | 340 c  |
| FWC         | 197           | 1756 ab     | 1953 ab|
| PMC         | 483           | 2106 a      | 2589 a |
| CMC         | 198           | 727 abc     | 925 b  |
| IF          | 158           | 1630 ab     | 1788 ab|
| NF          | 233           | 687 abc     | 920 b  |

Note: Values of the same parameter followed by the same letter are not significantly different (Tukey–Kramer test, p < .05, n = 4).

*AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC15, AC incorporation in the top 15 cm; AC5, AC incorporation in the top 5 cm.*
The results of incubation test (Figure 2) suggest that AC can supply N to potatoes less than CMC during the initial growth period due to N immobilization in the AC incorporated soil but AC can supply N to potatoes more effectively than CMC in the latter growth period because N mineralization from AC increased markedly from 4 weeks on. Such N mineralization pattern of AC will be related to the result that the ANUE was higher in the AC treatment than the CMC treatment.

Potato tuber yield was significantly related to total N uptake by potato (aboveground plus tuber) in both years (Figure 5), suggesting that the relationships between potato yield and N uptake in AC treatments were similar to the relationships in the other treatments. Although AC application inhibited potato early growth, N from AC seems to be used by potato plants and to contribute to tuber growth.

**Effects of AC application on weed growth**

The numbers of weeds, dry weight, and N uptake by weeds were lower in the AC application treatments than in the others (Figures 7 and 8; Table 4). Although AC did not suppress the emergence of monocot weeds in 2009 (Figure 6B-2), it suppressed the emergence of dicot weeds during 0–34 DAP, but not during 35–51 DAP (Figure 6C-2). Although the rate of increase of weed cover was lower in AC treatments during both 0–34 DAP and 35–51 DAP (Figure 6A-2), this may have been caused by the slow development of weed leaves in the AC treatments. These results suggest the suppressive effect of AC on dicot weed emergence and growth. In contrast, FWC, PMC, and CMC application did not suppress potatoes or weeds. Thus, AC has unique inhibitory effects on weed emergence and growth that other composts do not have.

Weed emergence and dry weight were reduced by the incorporation of a compost of green tea waste–rice bran, and some aromatic plants as green manure (Dhima et al., 2009; Khan et al., 2007). The presence of germination-inhibiting compounds (such as fatty acids, phenolic acids) in composts and animal wastes has been reported previously (Aso et al., 2004; DeVleeschawer et al., 1981; Marambe et al., 1993; Schuman & McCalla, 1976). Based on the studies, there is a possibility that suppression of weed emergence and growth occurred in the AC treatment plots was caused by germination-inhibiting compounds in AC or generated in the soil mixture. Separation and identification of germination-inhibiting compounds from AC are forthcoming challenges.

Khan et al. (2007) reported that rice bran more effectively inhibited the germination and growth of dicot crops (radishes, tomatoes, and lettuce) than of a monocot crop (oats), and there are additional reports that the plant growth inhibitory effects of compost vary depending on plant species (e.g. Nagaoka et al., 1996). Application of AC suppressed dicot weeds more efficiently than monocot weeds (Figure 6B and C). Although the reason for this difference was not clear, it may have been related to the species-specific inhibition by compounds included in AC or to the difference in emergence time of monocot and dicot weeds. At 17 DAP in IF, the number of dicot weeds (220 plants m−2) was higher than the number of monocot weeds (40 plants m−2). The germination and emergence rates during the early growth of potatoes were higher for dicot than monocot plants in our field experiments. Therefore, many dicot seeds seemed to germinate when the concentration of growth inhibitors derived from AC was high, and they were therefore affected more severely by the inhibitors. However, to confirm the mechanism of weed suppression, it will be necessary to perform controlled germination trials with known quantities of monocot and dicot seeds.

By 51 DAP, fewer dicot weeds had emerged in AC5 plots than in AC15 plots (Figure 7). The total N uptake by weeds was significantly lower in AC5 than in AC15 (Table 4). These results suggest that the surface application of AC can more effectively inhibit weed emergence than deep incorporation. This may be due to the lower inorganic N concentration caused by greater N immobilization and higher level of growth inhibitors at the soil surface in the AC5 plots, resulting in greater suppression of weed emergence. On the other hand, the potato emergence rate was higher in AC5 than in AC15 (Figure 3A). Therefore, AC surface application seems to have a positive potential for potato production and weed suppression.

**Conclusions**

We observed positive effects of food waste AC application on N uptake and tuber yield of potato. Moreover, the N supply capacity of the AC used in this study was higher than that of CMC and similar to that of FWC and PMC. Therefore, like FWC and PMC, AC appears to be useful for potato production through provision of an effective N source. Potato shoot emergence was delayed by AC, particularly just after incorporation, but potato yield was not inferior to the other treatments. In addition, the emergence and growth of weeds were suppressed by AC application, particularly in the case of surface application. According to these findings, AC serves two important functions: supplying N to the potato crop in fields and suppression of weed emergence. To improve crop productivity and achieve more effective weed suppression, it will be necessary to identify the substances contained in AC that inhibit plant growth in order to optimize the timing and rate of application for various crops.
Abbreviations

AC, acidulocompost; DAP, days after planting; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_{5}, AC incorporation in the top 5 cm.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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*In Japanese with English summary

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