Plant Production Science

ISSN: 1343-943X (Print) 1349-1008 (Online) Journal homepage: https://www.tandfonline.com/loi/tpps20

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

Naomi Asagi, Keisuke Minamide, Toru Uno, Masanori Saito & Toyoaki Ito

To cite this article: Naomi Asagi, Keisuke Minamide, Toru Uno, Masanori Saito & Toyoaki Ito (2016) Acidulocompost, a food waste compost with thermophilic lactic acid fermentation: its effects on potato production and weed growth, Plant Production Science, 19:1, 132-144, DOI: 10.1080/1343943X.2015.1128092

To link to this article: https://doi.org/10.1080/1343943X.2015.1128092

Published online: 27 Feb 2016.

PLANT PRODUCTION SCIENCE, 2016
VOL. 19, NO. 1, 132–144
http://dx.doi.org/10.1080/1343943X.2015.1128092

AGRONOMY & CROP ECOLOGY

OPEN ACCESS

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

Naomi Asagi[a,b], Keisuke Minamide[a,c], Toru Uno[a], Masanori Saito[a] and Toyoaki Ito[a]

[a]Graduate School of Agricultural Science, Tohoku University, 232-3 Yomogida, Naruko-onsen, Oosaki, Miyagi 989-6711, Japan; [b]College of Agriculture, Ibaraki University, 3-21-1 Chuo, Ami, Inashiki, Ibaraki 300-0393, Japan; [c]Ishikawa Prefectural Office, 1-1 Kuratsuki, Kanazawa, Ishikawa, 920-8580, Japan

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.

ARTICLE HISTORY
Received 30 November 2014
Revised 14 March 2015
Accepted 3 September 2015

KEYWORDS
Cattle manure compost; inorganic fertilizer; nitrogen; poultry manure compost; weed control

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

CONTACT Toyoaki Ito toyoaki@bios.tohoku.ac.jp

Table 1. Chemical characteristics of the composts applied to soils in the two years.

Composts	pH (H_2O)	EC[a] (dS m^{-1})	Total C	Total N	Available N[b]	Total P_2O_5	Total K_2O	C/N
			(g kg^{-1})					
2008								
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
2009								
Acidulocompost	4.2	5.4	507	47.8	1.6 (1.1)	8.5	7.4	10.6
Food waste compost	8.0	6.6	328	48.1	9.1 (1.5)	39.0	12.9	6.8
Poultry manure compost	8.6	7.6	274	42.8	15.4 (11.3)	55.5	40.2	6.4
Cattle manure compost	9.1	3.7	380	23.4	1.0 (1.0)	19.3	42.6	16.2

[a]EC, electrical conductivity.
[b]Available 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.
[c]Values in parentheses are contents of uric acid N in composts.

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

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 (H_2O) 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

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

		Compost (g m^{-2})				IF (g m^{-2})		
Treatment[a]	Compost and IF application method	Dry matter	N	P_2O_5	K_2O	N	P_2O_5	K_2O
AC_{15}	Incorporation[b]	581	27.8	4.9	4.3	0	13.1	8.7
AC_5	Surface application[c]	581	27.8	4.9	4.3	0	13.1	8.7
FWC	Incorporation	878	27.8	22.6	7.4	0	0	5.6
PMC	Incorporation	650	27.8	36.1	26.1	0	0	0
CMC	Incorporation	1,186	27.8	22.9	50.5	0	0	0
IF	Incorporation	0	0	0	0	10.0	18.0	13.0
NF		0	0	0	0	0	0	0

[a]AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer.
[b]Incorporation with compost and IF to a depth of 0–15 cm.
[c]Incorporation with compost to a depth of 0–5 cm and with IF to a depth of 0–15 cm.

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:

N mineralization rate (%) = [(mineralized N in soil mixed with compost – mineralized N in soil without compost) / total compost N added] × 100 (1).

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: AC_{15} (incorporation of AC to a depth of 0–15 cm), AC_5 (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. Table 2 shows the application rates. In the IF treatment, N, P_2O_5, and K_2O were incorporated into the top 15 cm as urea, superphosphate, and potassium sulfate at the same application rates as those used in conventional potato cultivation in Hokkaido, Japan. In each compost treatment, compost was applied so that the application rates of total N derived from compost were 27.2 and 27.8 g N m^{-2} in 2008 and 2009, respectively. These values were determined so that the input of available N (uric acid N plus inorganic N) in PMC (Table 1) equaled those in IF (10.0 g N m^{-2}). Superphosphate and potassium sulfate were added into the top 15 cm so that the application rates of P_2O_5 and K_2O in the compost treatments were more than those in the IF treatment.

Cultivation

In each treatment plot, we installed a bottomless wooden frame (0.9 m^2 = 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.

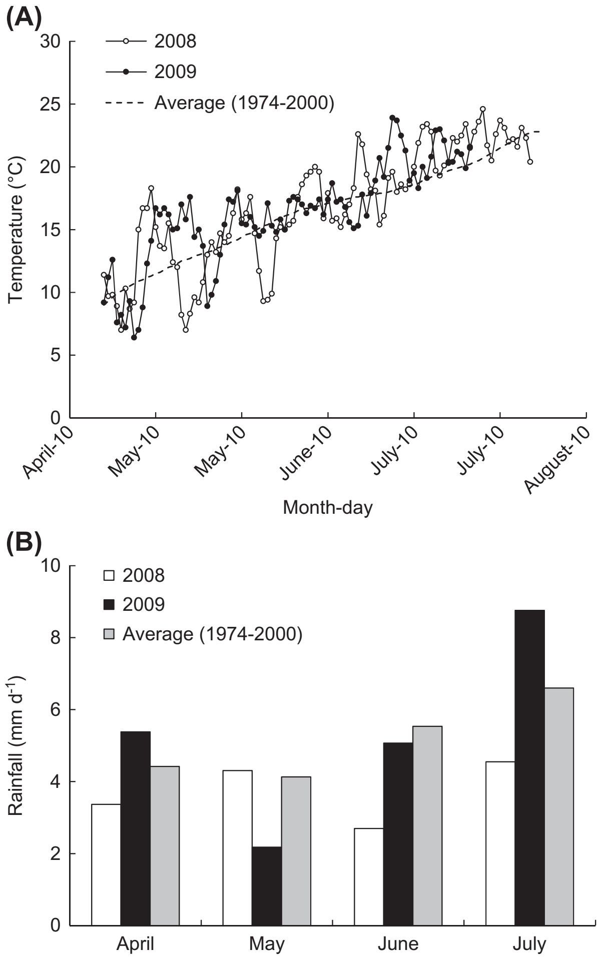

Figure 1. (A) Mean daily temperature and (B) total monthly rainfall at Osaki, Miyagi, Japan, during the potato cultivation period.

Sampling and measurements

Soil pH (H_2O)

Each of soils (depth of 0–5 cm and 5–15 cm) was collected at 18 DAP in 2008, and the pH (H_2O) was measured with a pH meter using a suspension of soil and deionized water at a ratio of 1:2.5.

Potatoes

The rates of potato emergence (sprouting) were measured during the first month after planting. Potato plant height (= the distance from the soil surface to the highest point of potato plant) was measured with a ruler from 30 to 80 DAP. Aboveground plant parts and tubers were collected at harvest, and we recorded the number of tubers, the aboveground weight (leaves plus stems), total tuber yield, and the yield of marketable tubers (>60 g each). We then oven-dried the aboveground parts and tubers at 70 °C and ground them into powder. We determined the total N concentration in these subsamples using an NC analyzer (Sumigraph NC-80).

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:

ANUE (%) = [(total N uptake in compost or IF treatment – total N uptake in NF treatment) / amount of N applied with compost or IF] × 100 (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 P_2O_5 and K_2O 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

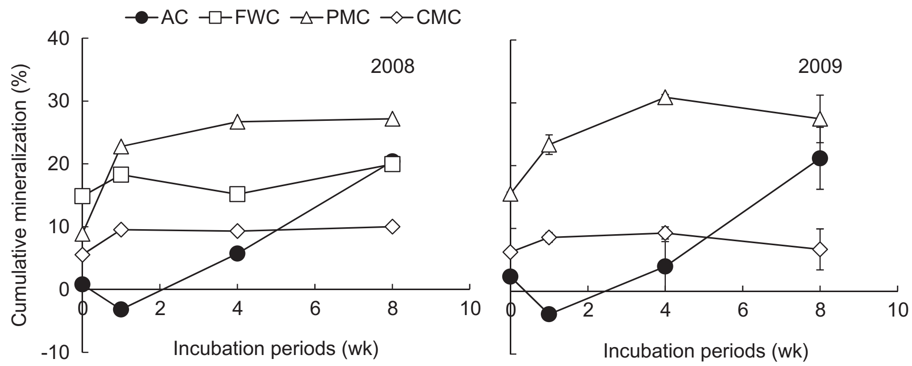

Figure 2. Cumulative amounts of mineralized N (percentage of the initial compost N that was added) in soils mixed with each compost. AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost. Values represent means ($n = 2$) for the composts used in 2008. Values are mean ± SEM ($n = 3$) in 2009. Mineralization rates of FWC were not analyzed in 2009.

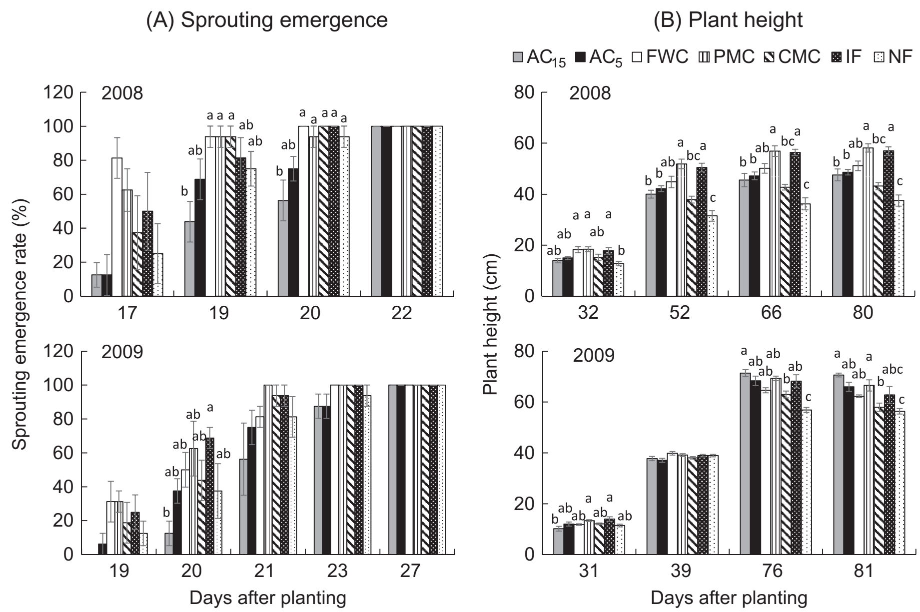

Figure 3. Temporal changes in (A) potato sprouting emergence rate and (B) plant height in 2008 and 2009. Values are mean ± SEM ($n = 4$). Bars labeled with the same letter do not differ significantly (Tukey–Kramer test, $p < .05$, $n = 4$). AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

in 2008. The mineral N content at 0 d of incubation was highest in FWC and lowest in AC. In the soil incubated with AC, net immobilization of N was observed after 1 wk, but the cumulative N mineralization gradually increased thereafter, reaching 20.4% (2008) and 21.2% (2009) of the N in the added compost after 8 wk. In soils incubated with FWC, PMC, and CMC, no N immobilization was observed. Cumulative N mineralization increased, reaching 20.0% in FWC (2008), 27.2% (2008), and 27.4% (2009) in PMC, and 10.0% and 6.7% in CMC after 8 wk. Thus, the cumulative N mineralization rate during 8 wk of incubation in soil with AC was similar to that with FWC, lower than with PMC, and higher than with CMC.

Soil pH (H_2O) at 18 DAP in 2008

The pH (H_2O) 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 (H_2O) 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 (H_2O) 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 AC_5 at 19 DAP, and in AC_{15} at 20 DAP (Figure 3A). In 2009,

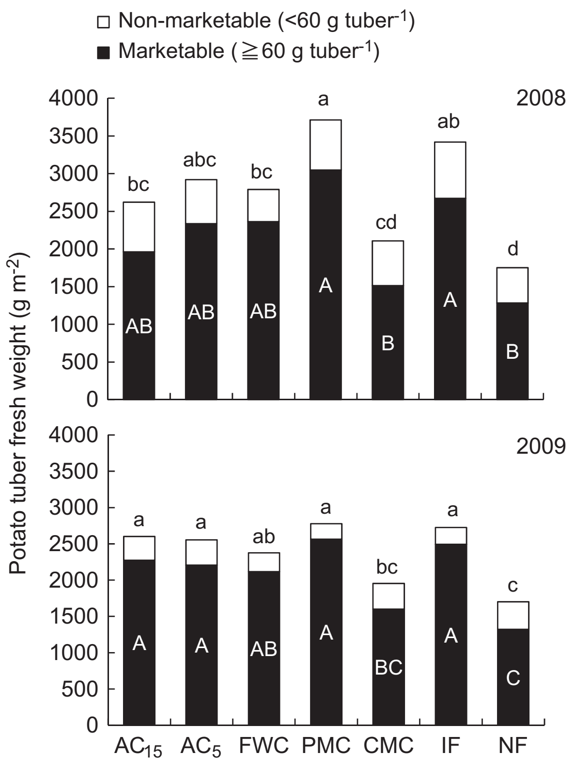

Figure 4. Potato tuber yield at harvest in 2008 and 2009. Bars labeled with the same lowercase letters do no differ significantly in total tuber weight, and bars with the same capital letters do not differ significantly in marketable tuber weight (Tukey–Kramer test, $p < .05$, $n = 4$). AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

it reached 50% in FWC, PMC, and IF at 20 DAP, and in AC_{15}, AC_5, CMC, and NF at 21 DAP. Thus, potato emergence in AC_{15} and AC_5 was delayed for 2–3 d in 2008 and for 1 d in 2009 compared with FWC, PMC, and IF. However, as in the other treatments, the emergence rates in AC_{15} and AC_5 eventually reached 100% in both years. Emergence in CMC and NF was delayed for 1 d in both years, but that in FWC and PMC was not delayed, compared with IF. The emergence in AC_{15} in both years tended to be delayed compared with AC_5.

Potato plant height was higher in PMC and IF, and lower in CMC and NF through cultivation period in 2008 (Figure 3B). Plant height in AC_{15} and AC_5 in 2008 was not significantly different from that in the other treatments at 32 DAP, but it was significantly lower than in PMC and IF and higher than in CMC and NF at 52, 66, and 80 DAP. In 2009, plant height tended to be higher in AC_{15}, and lower in CMC and NF through cultivation period. Plant height at 31 DAP in 2009 was significantly lower in AC_{15} than in PMC and IF, but was not significantly different between AC_5 and the other compost treatments or IF. At 76 and 81 DAP in 2009, the plant heights in AC_{15} and AC_5 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 AC_{15} and AC_5 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 AC_{15} and AC_5 was significantly higher than in NF in 2008, and there were no significant differences in yield among AC_{15}, AC_5, FWC, and IF (Figure 4). Marketable tuber yield in AC_{15} and AC_5 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 AC_{15} and AC_5 was significantly higher than in NF and CMC. There were no significant differences in yield among AC_{15}, AC_5, FWC, PMC, and IF in 2009. Marketable tuber yield in AC_{15} and AC_5 was significantly higher than that in CMC and NF.

There were no significant differences in tuber yield between AC_{15} and AC_5. 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 AC_{15} and AC_5 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 AC_{15} and 10.4 and 12.3% for AC_5. 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 AC_{15} and AC_5. 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 AC_{15} and AC_5 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 AC_{15} and AC_5 than in other treatments, and significant differences between AC treatments and IF

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

Treatment[a]	N uptake (g m^{-2}) Aboveground	Tubers	Total	ANUE (%)
2008				
AC_{15}	1.11 ab	6.89 a	8.00 a	10.8 b
AC_5	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				
AC_{15}	1.52 ab	7.48 ab	9.00 a	12.7 b
AC_5	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, $p < .05$, $n = 4$).
[a]AC, acidulocompost; 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.

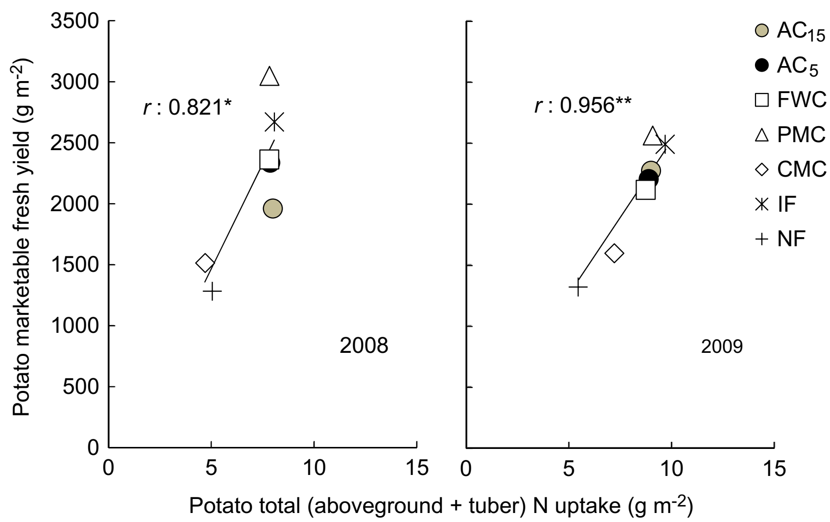

Figure 5. Relationship between potato (aboveground plus tuber) N uptake and marketable tuber fresh yield in 2008 and 2009. *r* denotes Pearson correlation coefficients, *$p < .05$, **$p < .01$. AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

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 AC_{15} and AC_5 than in the other treatments both during 0–34 DAP and 35–51 DAP (Figure 6A-2). There were significant differences between IF and AC_{15} or AC_5 during 0–34 DAP and between IF and AC_5 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.

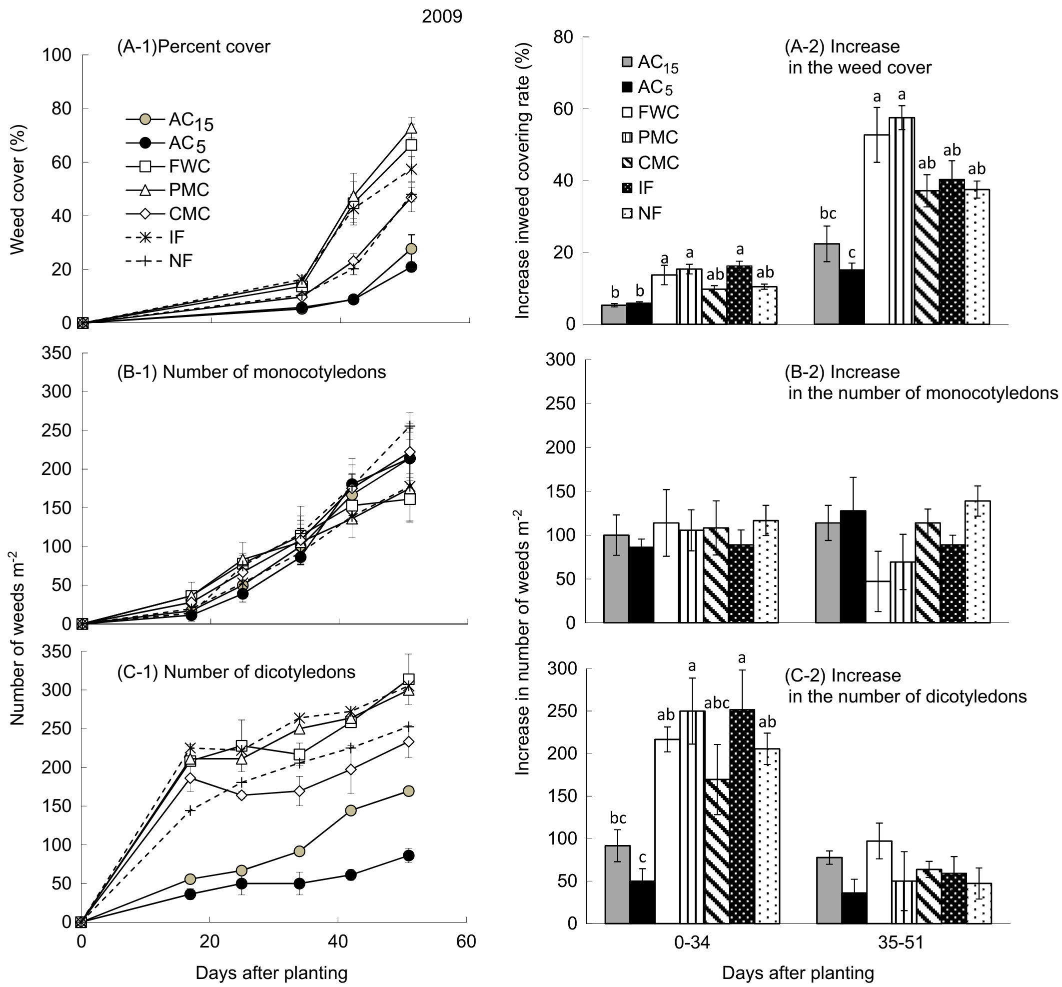

Figure 6. Changes in (A-1) weed cover, (B-1) number of monocot weeds, (C-1) number of dicot weeds, and increases in (A-2) weed cover and numbers of (B-2) monocot weeds and (C-2) dicot weeds during 0–34 and 35–51 DAP in the potato field soils in 2009. Values are means ± SEM ($n = 4$). Values labeled with the same letter do not differ significantly (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; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

The total number of monocot weeds at 51 DAP was significantly lower in AC_{15} and AC_5 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 AC_{15} and AC_5 than in the other treatments in both years, with a significant difference between AC_5 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 AC_{15} and AC_5 than in IF (Figure 7). The number of *P. blumei* in 2008 was significantly lower in AC_5 than in IF. The number of *O. biennis* in 2009 was significantly lower in AC_{15} and AC_5 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 AC_{15} and AC_5 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 AC_{15} and AC_5 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 AC_5 than in AC_{15} (Table 4). Moreover, the number of weeds (Figure 7) and weed aboveground dry weight (Figure 8) were lower in AC_5 than in AC_{15}. Thus, the AC application method (deep versus surface incorporation) affected weed growth.

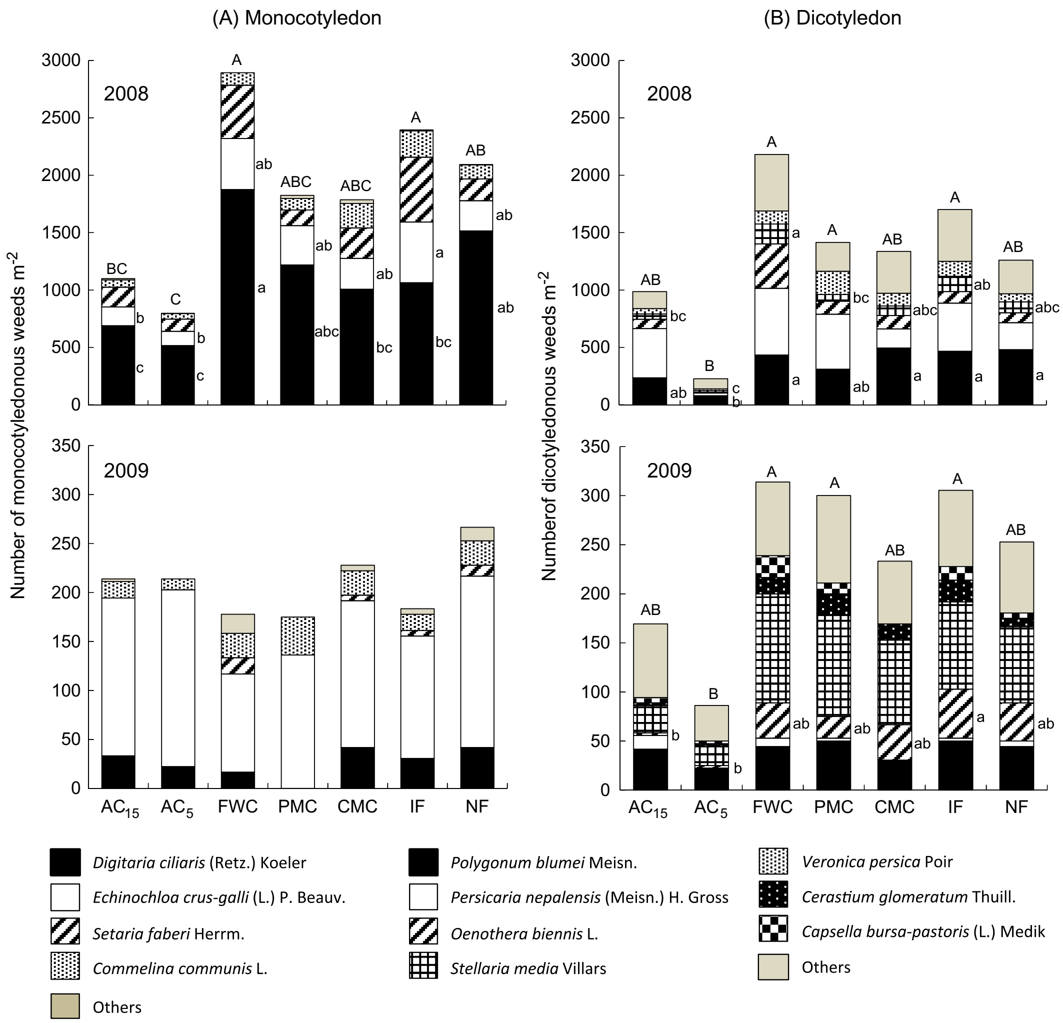

Figure 7. Numbers and species of (A) monocot and (B) dicot weeds in 2008 and 2009. Bars labeled with the same capital letters do not differ significantly in total number of weeds, and bars with the same lowercase letters do not differ significantly in number of each weed species (Tukey–Kramer test, $p < .05$, $n = 4$). AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

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 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).

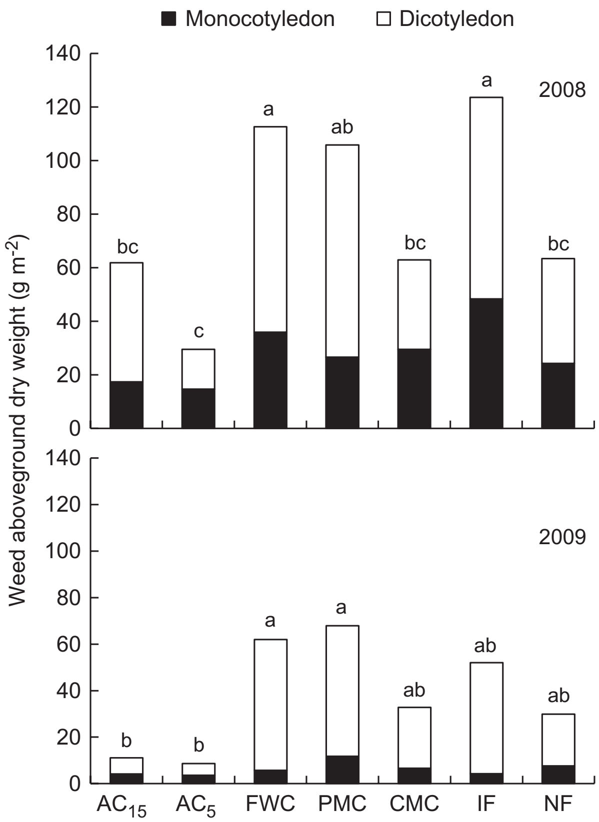

Figure 8. Weed aboveground dry weight at 51 DAP in 2008 and 2009. Values labeled with the same letter do not differ significantly (Tukey–Kramer test, $p < .05$, $n = 4$). AC, acidulocompost; FWC, food waste compost; PMC, poultry manure compost; CMC, cattle manure compost; IF, inorganic fertilizer; NF, no fertilizer; AC_{15}, AC incorporation in the top 15 cm; AC_5, AC incorporation in the top 5 cm.

Effects of AC application on growth and tuber yield of potatoes

Tatenai et al. (2006) reported that soil pH (H_2O) was decreased by AC application, but in the present study, AC application did not decrease the soil pH (H_2O) 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 AC_{15} and AC_5 than in the other treatments in both years, and potato plant height at 31 DAP in 2009 was also significantly lower in AC_{15} 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 AC_{15} than in AC_5 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 AC_{15} than in AC_5.

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 ^{15}N-labeled organic matter. The N uptake efficiencies of potatoes based on the ^{15}N 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[a]	N uptake (mg m^{-2})		
	Monocotyledon	Dicotyledon	Total
AC_{15}	170	255 bc	424 b
AC_5	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, $p < .05$, $n = 4$).
[a]AC, acidulocompost; 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.

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 AC_5 plots than in AC_{15} plots (Figure 7). The total N uptake by weeds was significantly lower in AC_5 than in AC_{15} (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 AC_5 plots, resulting in greater suppression of weed emergence. On the other hand, the potato emergence rate was higher in AC_5 than in AC_{15} (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.

Acknowledgments

This study was financially supported by Tohoku University, Japan (Project of Integrated Compost Science), and the Japanese Ministry of Education, Culture, Sports, Science and Technology. We also thank Star Engineering Co., Ltd., for providing the acidulocompost.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abdourhamane, T. A., et al. (2011). Impact of very low crop residues cover on wind erosion in the Sahel. *Catena, 85*, 205–214.
Asano, R., et al. (2010). Development and analysis of microbial characteristics of an acidulocomposting system for the treatment of garbage and cattle manure. *Journal of Bioscience and Bioengineering, 110*, 419–425.
Aso, S., et al. (2004). Variation of phenolic substances during the humification process of rice straw compost and the bioassay by rice plant seedling. *Japanese Journal of Soil Science and Plant Nutrition, 65*, 321–325.*
Bremner, J. M., & Keeney, D. R. (1965). Steam distillation methods for determination of ammonium, nitrate and nitrite. *Analytica Chimica Acta, 32*, 485–495.
Cayuela, M. L., et al. (2008). Potential of olive mill waste and compost as biobased pesticides against weeds, fungi, and nematodes. *Science of the Total Environment, 399*, 11–18.
DeVleeschawer, D., et al. (1981). Phytotoxicity of reuse compost. *Biocycle, 22*, 44–46.
Dhima, K. V., et al. (2009). Effects of aromatic plants incorporated as green manure on weed and maize development. *Field Crops Research, 110*, 235–241.
Errebhi, M., et al. (1998). Potato yield response and nitrate leaching as influenced by nitrogen management. *Agronomy Journal, 90*, 10–15.
Fiorentino, A., et al. (2003). Environmental effects caused by olive mill wastewaters: Toxicity comparison of low-molecular-weight phenol components. *Journal of Agricultural and Food Chemistry, 51*, 1005–1009.
Harada, Y., et al. (1993). Quality of compost produced from animal wastes. *Japan Agricultural Research Quarterly, 26*, 238–246.
Heinai, H., et al. (2009). Ammonia emission and carbon and nitrogen balances during acidulocomposting of garbage. *Journal of Integrated Field Science, 6*, 101–107.
Hemmi, H., et al. (2004). Molecular biological analysis of microflora in a garbage treatment process under thermoacidophilic conditions. *Journal of Bioscience and Bioengineering, 97*, 119–126.
Hidaka, H., et al. 2006. Effects of nitrogen forms of poultry manures on the growth of vegetables. *Japanese Journal of Soil Science and Plant Nutrition, 77*, 73–76.**
Ishidori, M., et al. (2005). Model study on the effect of 15 phenolic olive mill wastewater constituents on seed germination and vibrio fischeri metabolism. *Journal of Agricultural and Food Chemistry, 53*, 8414–8417.
Ito, T., & Saigusa, M. (1996). Characteristics of nonallophanic andisols at Tohoku University Farm. *Bulletin of the Experimental Farm, Tohoku University, 12*, 91–103.
IUSS Working Group WRB. (2006). World reference base for soil resource 2006 (2nd ed., World Soil Resources Reports No. 103). Rome: FAO.
Khan, M. A. I., et al. (2007). Evaluation of the upland weed control potentiality of green tea waste-rice bran compost and its effect on spinach growth. *American Journal of Agricultural and Biological Sciences, 2*, 142–148.
Kida, K., et al. (2004). Development of an application process for waste biomass. *Waste Management & Research, 15*, 77–88.*
Li, H., et al. (2003). Efficiency of soil and fertilizer nitrogen of a sod-potato system in the humid, acid and cool environment. *Plant Soil, 251*, 23–36.
MAFF. (2006). Biomass Nippon Total Strategy [Online]. Retrieved January 18, 2013, from http://www.maff.go.jp/j/biomass/pdf/h18_senryaku.pdf**
Marambe, B., et al. (1993). Identification and biological activity of germination-inhibiting long-chain fatty acids in animal-waste composts. *Plant Cell Physiology, 34*, 605–612.
Martins, O., & Dewes, T. (1992). Loss of nitrogenous compounds during composting of animal wastes. *Bioresource Technology, 42*, 103–111.
Mathur, S. P., et al. (1993). Determination of compost biomaturity. I. Literature review. *Biological Agriculture & Horticulture, 10*, 65–85.
Murakami, K., et al. (2007). The rapid estimation of available nitrogen in chicken manure compost by determination of uric acid. *Japanese Journal of Soil Science and Plant Nutrition, 78*: 85–87.**
Murphy, J., & Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta, 27*, 31–36.
Nagaoka, T., et al. (1996). Selective inhibitors of germination of legume seeds in activated sludge compost. *Plant Growth Regulation, 20*, 295–302.
Nakatsu, S., & Tamura, H. (2009). Effects of thirty years of continuous application of organic matter (cattle manure with bark and crop residues) on yield and quality of upland crops in light colored Andosol in Hokkaido. *Bullentin of the Hokkaido Prefectural Agricultural Experiment Station, 94*, 81–302.*
Nishino, T., et al. (2003). Acidulocomposting, an accelerated composting process of garbage under thermoacidophilic conditions for prolonged periods. *Journal of Environment and Biotechnology, 3*, 33–36.
Schuman, G. E., & McCalla, T. M. (1976). Effect of short-chain fatty acids extracted from beef cattle manure on germination and seedling development. *Applied and Environmental Microbiology, 31*, 655–660.
Star Engineering Co., Ltd. (2016). Retrieved January 18, 2013, from http://www.stareng.co.jp/bs_gomi/bioclean-jirei.html **

Tanahashi, T., & Yano, H. (2004). The method of presuming the effect of nitrogen based on the nitrogen content of a poultry manure compost. *Japanese Journal of Soil Science and Plant Nutrition, 31*, 257–260.**

Tanahashi, T., et al. (2010). Magnesium ammonium phosphate in cattle and swine manure composts and extraction method for its evaluation. *Japanese Journal of Soil Science and Plant Nutrition, 84*, 329–335.*

Tatenai, S., et al. (2006). Effects of acidulocompost application on the growth and yield of potato belongs to acidophilic crops. *Bulletin of Integrated Field Science Center , 22*, 25–29.**

Tran, S. T., & Giroux, M. (1991). Effects of N rates and harvest dates on the efficiency of 15 N-labelled fertilizer on early harvested potatoes (*Solanum tuberosum* L.). *Canadian Journal of Soil Science, 71*, 519–532.

Truog, E. (1930). The determination of the readily available phosphorus of soil. *Agronomy Journal, 22*, 874–882.

Umemoto, H., et al. (2012). Investigation of maturity indices of food waste compost. *Japanese Journal of Soil Science and Plant Nutrition, 83*, 664–672.*

Ushio, S., et al. (2000). Nitrogen decomposition rate of animal waste composts and dry wastes for 141 days in summer, and their estimation. *Japanese Journal of Soil Science and Plant Nutrition, 71*, 249–253.**

Ushio, S., et al. (2004). The spreadsheets that show the characteristics of ingredient contents of animal waste compost and the proper rate of animal waste compost application. *Japanese Journal of Soil Science and Plant Nutrition, 75*, 99–102.**

Witter, E., & Lopez-Real, J. (1988). Nitrogen losses during the composting of sewage sludge, and the effectiveness of clay soil, zeolite, and compost in adsorbing the volatilized ammonia. *Biological Wastes, 23*, 279–294.

Yokota, T., et al. (2003). Measurement of total phosphorus and organic phosphorus contents of animal manure composts by the dry combustion method. *Soil Science and Plant Nutrition, 49*, 267–272.

*In Japanese with English summary

**In Japanese