New Function of Compost: Inhibitory Effect of Acidulo(R)compost on Weed Germination and Growth

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Abstract

Acidulo®compost (AC) is a type of compost derived from food waste processed under thermophilic and acidic conditions. Given this compost's high nitrogen content and potential to suppress weeds, its applicability in agriculture has been investigated. In this study, we evaluated the potential for AC to be used as a pre-emergent herbicide. Suppression of weed emergence was confirmed by applying AC to a cabbage field. Application of AC was particularly effective in suppressing the emergence of dicotyledonous weeds and had some effects on monocotyledonous weeds. The suppression was maintained until 30-40 days following transplanting, which is critical for weed control in cabbage cultivation. AC application to surface soil (5cm in depth) suppressed weed emergences more effectively than the application to the whole plow-layer of soil (15cm in depth). AC also adversely affected cabbage yields when applied in large amounts. To reduce the negative effects of AC on crop growth, an alternative method of AC application that replaces the AC-amended soil inside planting holes with AC-free soil was examined in a container experiment. AC application to the whole soil adversely affect the initial growth and the following cabbage head formation. The alternative AC application could mitigate adverse effects on initial growth, but partly affected the following stage. Therefore, AC has a potential to be used as an efficient biological weed control. However, further studies are necessary to determine the optimal AC application technique(s) and dose(s) for effectively suppressing weed growth while minimizing the effects on crop growth.

Introduction

A large amount of food waste is generated in home kitchens, restaurants, and school cafeterias. Food waste, typically, is treated by incineration or disposal in landfills, but it is increasingly being used as a renewable resource such as animal feed or fertilizer (compost). Following the enforcement and revision of the Food Waste Recycling Law, reuse as feed for animals could be the most effective method for processing food waste, but composting is also an important method, particularly in dealing with a mixture of various food wastes (Ministry of Agriculture, Forestry and Fisheries, 2012). An effective way to improve the low rate of household garbage recycling is on-site composting and agricultural use of the product (compost).

To process kitchen food waste (garbage), numerous composting apparatus have been developed that, typically, include heating and agitating devices to promote the decomposition of organic materials. However, several problems are associated with these devices, including foul odor emissions during composting and gradual decline in performance because of decrease in pH of the compost. To resolve these problems, Nishino et al. (2003) developed the Acidulo®composting method, whereby food wastes are treated under thermophilic and acidic conditions. This method enables continuous operation without periodic replacement of the substrate and also has the capacity to reduce odor emissions during composting. In the method, lactic acid bacteria comprise the majority of the microflora in the reactor (Asano et al., 2010; Hemmi et al., 2004). Greenhouse gas emissions from the process of Acidulo®composting from fish meal and the utilization of the compost were also evaluated (Tajima et al., 2013).

Previous studies evaluating the applicability of Acidulo®compost (AC; the product of the Acidulo®composting process) for agricultural purposes (Tatenai et al., 2006; Minamide et al., 2009) showed that the nitrogen (N) content in AC is high because of the relatively low emissions of NH_3 gas during composting and that AC showed relatively high supply capacity of N. In a field study on a summer crop (potato), Ito et al. (2008) showed that AC application could suppress emergence and growth of summer weeds. These results suggest that AC can be used as a substitute for chemical herbicides in organic farming systems, and thus, can assist in minimizing environmental pollution risks.

In this context, we conducted field cultivation experiments to evaluate whether AC is effective in controlling weeds and whether it affects crop growth.

Materials and Methods

Star Engineering Co., Ltd. (Ibaraki Prefecture, Japan) provided the AC, which was made from the food wastes of a food service center using the AC apparatus (maximum daily load of food waste: 500 kg). In the composter, food waste (vegetable only) was added daily to the base material (sawdust inoculated with the starter microorganism *Alicyclobacillus sendaiensis* strain NTAP-1) and processed under heating and agitating conditions (Nishino et al., 2003). The chemical properties of the AC used in 2011 were as follows: total carbon, 458 g C kg^{-1}; total nitrogen, 24 g N kg^{-1}; and C/N ratio, 19. The properties of the AC in 2012 were as follows: pH, 4.6; EC, 9.8 $dS{\bullet}m^{-1}$; total carbon, 459 g C kg^{-1}; total nitrogen, 30 g N kg^{-1}; C/N ratio, 15; and available P (Truog method), 2.5 g P_2O_5 kg^{-1}. Field studies were conducted in an arable field at the Field Science Center, Graduate School of Agricultural Science, Tohoku University. Soil (nonallophanic andosol) chemical properties were as follows: pH, 5.9; EC, 0.03 $dS{\bullet}m^{-1}$; total carbon, 35 g C kg^{-1}; total nitrogen, 2.3 g N kg^{-1}; and available P (Truog method), 329 mg P_2O_5 kg^{-1}.

The effect of AC on weed emergence and growth was examined in field studies. We incorporated chemical fertilizer ($N:P_2O_5:K_2O$ = 20:20:20 $g{\bullet}m^{-2}$) and lime into the entire plow layer of the soil (15 cm depth) over 2 years (Table 1). In 2011, we examined the effect of AC application rate on weed growth. AC was incorporated into the whole plow-layer of soil (15 cm in depth) at 0 (chemical fertilizer application, CF), 700 (AC700) and 1400 $g{\bullet}m^{-2}$ (AC1400) after making ridges. In 2012, we examined the effect of AC application methods (at a constant rate of 1000 $g{\bullet}m^{-2}$) on weed and crop (cabbage) growth. The application methods involved four treatments (Figure 1): (1) mixing AC with the whole plow-layer of soil when making ridges (AC-W), (2) mixing AC with the whole plow-layer of soil when making ridges, but subsequently replacing the soil inside holes (63 mL) for transplanting cabbage seedlings with AC-free soils (AC-Wr), (3) mixing AC with surface soil (5 cm in depth) after making ridges (AC-S), and (4) without AC application (chemical fertilizer application: CF). Cabbage seedlings (*Brassica oleracea* var. *capitata*, cv. 'YR Seishun'; Watanabe Seed Co., Japan) were transplanted 30 cm apart in double lines (45 cm between lines) in rows with 180 cm between rows in September 2011 and June 2012. Growth and yield of four cabbages were determined with five replications for each treatment in both years, except for cabbage yield in 2012 where only two cabbages per treatment were used for the measurements. Weed populations of monocotyledonous and dicotyledonous weeds were measured at the center of the ridge (30 cm × 30 cm).

To develop an alternative application method of AC that mitigates negative effects on cabbage growth, a container experiment was conducted. Soil was collected from another arable field at the Field Science Center, air-dried, mixed with chemical fertilizer

Table 1. Application rates of AC and chemical fertilizers in field studies.

		Acidulocompost		Chemical fertilizer		
		dry weight	N	Urea	Superphosphate	Potassium sulfate
		$g\ m^{-2}$	$g\ N\ m^{-2}$	$g\ N\ m^{-2}$	$g\ P_2O_5\ m^{-2}$	$g\ K_2O\ m^{-2}$
2011	CF			20	20	20
	AC700	700	16.5	20	20	20
	AC1400	1400	32.9	20	20	20
2012	CF			20		20
	AC-W	1000	29.8	20		20
	AC-Wr	1000	29.8	20		20
	AC-S	1000	29.8	20		20

AC, Acidulo®compost; AC700 (AC1400), AC application at 700 (1400) $g{\bullet}m^{-2}$; AC-W, AC application to whole plow layer of soil; AC-Wr, AC application to whole plow layer of soil with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; AC-S; surface application (5-cm depth) of AC; CF, chemical fertilizer application (control).

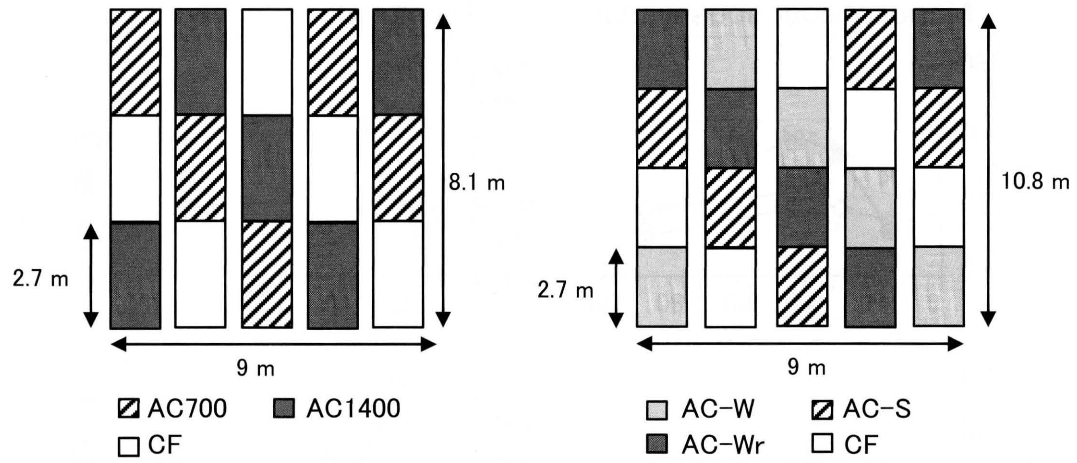

Figure 1. Designs of field studies conducted in 2011 (left) and 2012 (right).

AC, Acidulo®compost; AC700 (AC1400), AC application at 700 (1400) g•m^{-2}; AC-W, AC application to whole plow layer of soil; AC-Wr, AC application to whole plow layer of soil with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; AC-S; surface application (5-cm depth) of AC; CF, chemical fertilizer application (control)

($N:P_2O_5:K_2O$ = 0.22:0.22:0.22 g•kg^{-1}), and filled in a 1/5000 a Wagner pot (1830 g air-dried soil per pot). In the experiment, three AC application methods (at a constant rate of 15.3 g•kg^{-1}) were compared: AC application (AC), AC application with the soil in the vicinity of the planting hole (63 mL) replaced with AC-free soil (AC-r), and with no AC application (chemical fertilizer application, CF; see Figure 4). Three pots were used for each treatment. After the adjustment of water content to 40% of the water holding capacity, a cabbage seedling (*Brassica oleracea* var. *capitata*, cv. 'YR Seishun'; Watanabe Seed Co., Japan) was transplanted into each pot and cultivated in a greenhouse.

Experimental results were statistically verified using one-way analysis of variance (R ver. 3. 0. 2; R Development Core Team, 2008). Means were compared between treatments by Tukey's test at a confidence level of $P < 0.05$.

Results and Discussions

Weed emergence suppression by AC application

In the field studies, weed emergence was suppressed by AC application (Figure 2). In 2011, following AC application, the populations of monocotyledonous weeds decreased, albeit not significantly, to 56% (AC700) and 47% (AC1400) of the control (CF) treatment. Emergence and growth of dicotyledonous weeds were significantly suppressed to 48% (AC700) and 32% (AC1400) by AC application. The suppression of weed emergence by AC applications was maintained until 45 days after transplanting. Weed populations under cabbage leaves in the control (CF) also decreased 1 month after transplanting. In 2012, monocotyledonous weed populations were low (not significant) in three AC application methods 16 days after transplanting. The populations of dicotyledonous weeds were significantly suppressed in AC-W (43%), AC-Wr (57%), and AC-S (29%) compared to that in CF 16 days after transplanting and remained lower until 30 days after transplanting. These results suggest that the initial 30-40 days following transplanting are critical for weed control in cabbage crops and that AC application effectively controlled weed emergence in that period.

Among weed species, the emergence of the monocotyledonous weeds *Digitaria ciliaris* and *Echinochloa crus-galli*, and the dicotyledonous weeds *Chenopodium album*, *Stellaria neglecta*, and *Polygonum longisetum* were relatively (though not significantly) suppressed by AC applications in 2012 (Figure 3). Because these species accounted for a large proportion of weeds in summer at the study sites, it is unclear whether the reason for these results could be that AC application specifically affected the growth of these weed species or that the effects were nonspecific, but the AC application period was appropriate for suppressing the emergence of these species.

Compost is typically defined as the aerobically stabilized or matured organic matter and is used for crop

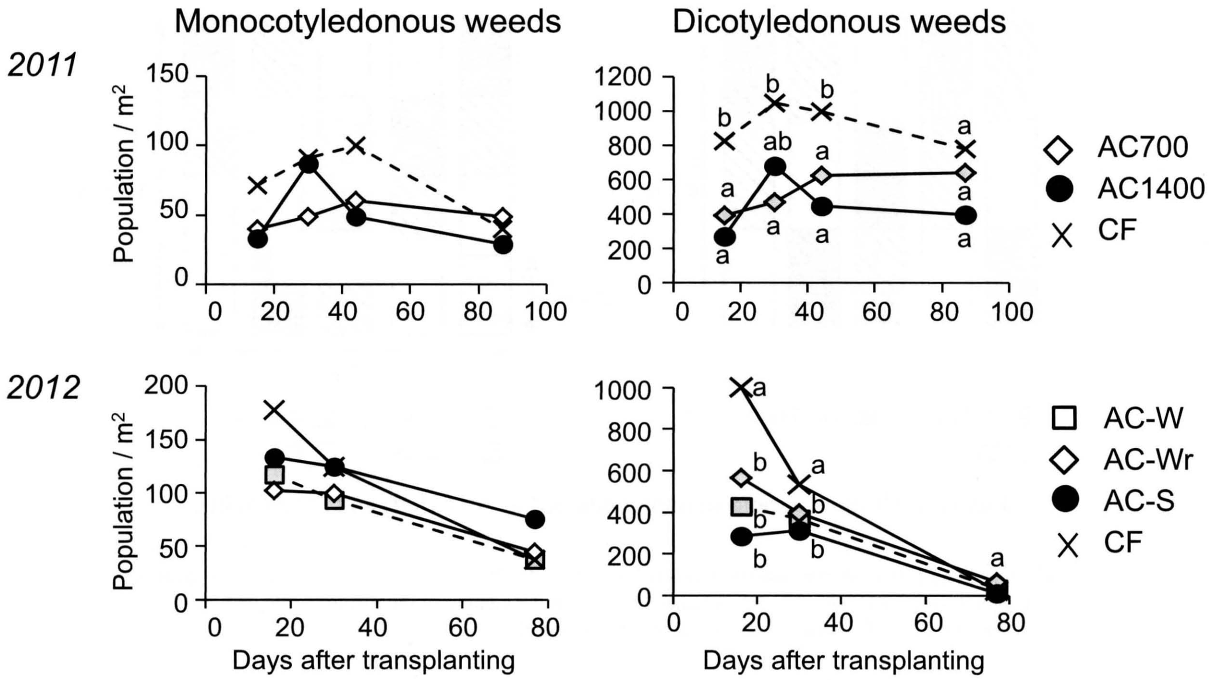

Figure 2. Monocotyledonous and dicotyledonous weed populations in cabbage cultivation.

Means followed by different letters are significantly different at $P < 0.05$ based on Tukey's test. AC, Acidulo®compost; AC700 (AC1400), AC application at 700 (1400) g•m^{-2}; AC-W, AC application to whole plow layer of soil; AC-Wr, AC application to whole plow layer of soil with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; AC-S; surface application (5-cm depth) of AC; CF, chemical fertilizer application (control)

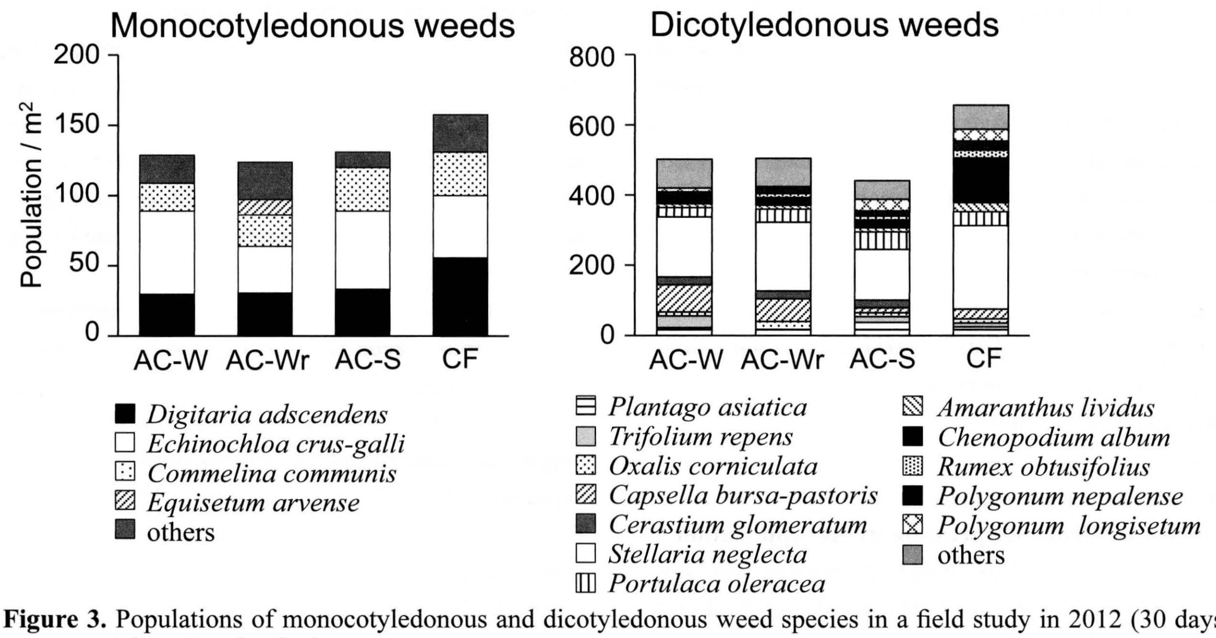

Figure 3. Populations of monocotyledonous and dicotyledonous weed species in a field study in 2012 (30 days after transplanting).

AC, Acidulo®compost; AC-W, AC application to whole plow layer of soil; AC-Wr, AC application to whole plow layer of soil with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; AC-S; surface application (5-cm depth) of AC; CF, chemical fertilizer application (control).

Table 2. Cabbage yields in field studies in 2011 and 2012.

		Head fresh weight g			Leaf fresh weight g		
2011	CF	387.5	(90.7)	a	483.8	(100.3)	a
	AC700	403.9	(160.3)	a	511.1	(93.1)	a
	AC1400	247.2	(88.5)	b	476.6	(83.0)	a
2012	CF	676.2	(48.2)	a	300.7	(138.9)	a
	AC-W	536.1	(112.5)	a	303.1	(202.6)	a
	AC-Wr	555.3	(67.1)	a	228.7	(299.2)	a
	AC-S	612.9	(129.3)	a	309.2	(257.4)	a

Numbers in parentheses indicate standard deviation. Means followed by different letters are significantly different at $P < 0.05$ based on Tukey's test. AC, Acidulo®compost; AC700 (AC1400), AC application at 700 (1400) $g{\bullet}m^{-2}$; AC-W, AC application to whole plow layer of soil; AC-Wr, AC application to whole plow layer of soil with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; AC-S; surface application (5-cm depth) of AC; CF, chemical fertilizer application (control).

cultivation to enhance plant growth. Thus, mature composts commonly have almost no negative effects on crop growth. A lot of studies have been conducted for compost maturity (Hase and Kawamura, 2012; Jiménez and Garcia, 1989; Komilis and Tziouvaras, 2009). On the other hand, immature compost may be detrimental to plant growth by releasing high concentrations of acetic, butyric, propionic acids, or other organic compounds (Devleeschauwer et al., 1981; Marambe et al., 1993; Ozores-Hampton et al., 2001; Schuman and Mccalla, 1976). However, there is considerable potential for the phytotoxic ability of immature composts as a biocontrol agent against weeds. Ozores-Hampton et al. (2001) reported that the mulch of immature municipal solid waste-biosolids (MSW) compost could suppress weed germination and subsequent weed growth in greenhouse and field experiments. In their field study, the mulch at 7.5cm or greater thickness completely inhibited weed germination and growth for 8 months without affecting zucchini yield, due to the physical covering for the soil surface and/or the phytotoxic activity of the immature MSW compost. In our studies, AC applications significantly suppressed weed emergences. These findings suggest that phytotoxic ability of AC or immature composts can be available for weed control.

Effective AC application method to mitigate phytotoxic effects on cabbage growth

Since AC derived from garbage has phytotoxic potential, it is not only useful for weed control but is also potentially harmful to crop growth. In 2011, cabbage growth was not affected by the application of a relatively small amount of AC (AC700: 700 $g{\bullet}m^{-2}$) but was significantly affected by the application of a larger amount in 2011 (AC1400: 1400 $g{\bullet}m^{-2}$; Table 2). In 2012, we found no significant differences in cabbage yields, but the head weight was relatively low in AC-W (79%) and AC-Wr (82%), whereas that in AC-S (91% of CF) was similar to CF. A reason for lower effects on cabbage growth in the AC-S treatment could be that the surface application of AC (at 5 cm depth) scarcely affects root development below 5 cm. These results suggest that although AC application can adversely affect not only the growth of weeds but also the growth of cabbages, it is possible to minimize adverse effects of AC on cabbage growth by optimizing the dose and the method of application.

An alternative method of AC application to mitigate adverse effects on cabbage growth was examined by comparing the common treatment (AC: AC incorporation into the whole soil), the alternative treatment (AC-r: replacement of the soil inside seedling holes with AC-free soil), and control (CF; Figure 4). Cabbage growth was significantly suppressed in AC from 9 (for leaf length and width) or 14 days after transplanting (for shoot length), while the cabbage in AC-r grew well, similar to that in the CF until 22 days after transplanting (Table 3). This suggests that the replacement of the soil in the planting hole with AC-free soil can mitigate the adverse effects of AC on the initial growth of cabbage. However, cabbage growth in AC-r was significantly suppressed from 22 days

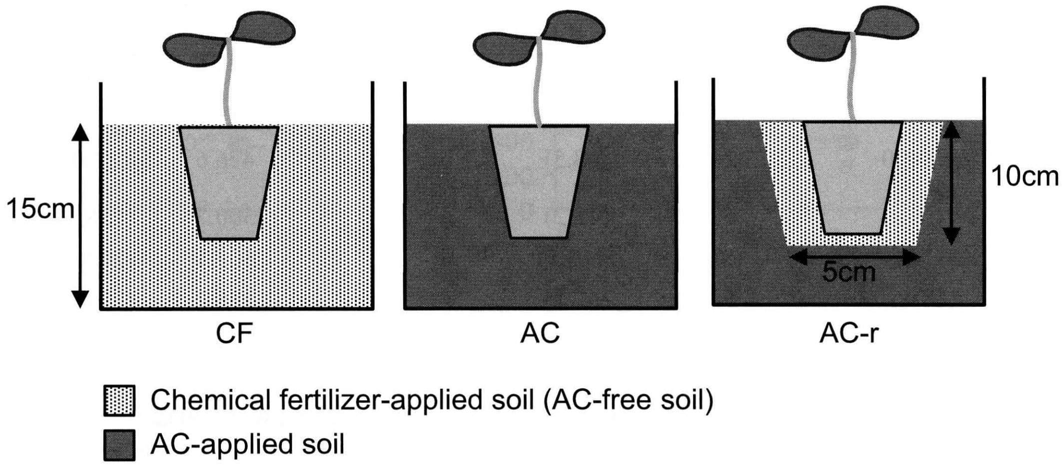

Figure 4. Acidulo®compost application methods in a container (1/5000 a Wagner pot) experiment in 2011.

AC, Acidulo®compost; AC, AC application; AC-r, AC application with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; CF, chemical fertilizer application (control).

Table 3. Cabbage growth in a container experiment in 2012.

		Days after transplanting						
		0	9	14	22	29	40	43
No. of leaves	CF	5.0 a	7.0 a	8.3 a	11.5 a	13.8 a	13.8 a	12.0 a
	AC	5.3 a	6.3 a	7.8 a	10.8 a	13.3 a	13.5 a	12.0 a
	AC-r	5.3 a	6.5 a	7.8 a	10.5 a	12.8 a	13.0 a	11.3 a
Shoot length (mm)	CF	16.5 a	17.9 a	20.9 b	25.3 b	26.8 a	28.8 b	27.9 b
	AC	15.1 a	16.4 a	16.6 a	22.1 a	24.9 a	26.1 a	25.6 a
	AC-r	14.9 a	16.4 a	18.9 ab	23.7 ab	25.4 a	26.3 a	25.8 a
Leaf length (mm)	CF	8.9 a	9.7 b	12.2 b	15.4 b	17.6 b	18.1 b	17.3 a
	AC	8.2 a	8.7 a	9.8 a	13.2 a	16.0 a	16.6 ab	16.8 a
	AC-r	7.9 a	9.4 ab	11.4 ab	14.8 b	15.4 a	16.0 a	16.3 a
Leaf width (mm)	CF	5.3 a	6.5 b	9.6 b	12.6 a	14.6 a	16.4 b	16.3 b
	AC	5.0 a	5.4 a	7.5 a	11.6 a	16.2 a	14.5 a	14.4 a
	AC-r	4.8 a	6.2 b	9.2 b	13.4 a	13.8 a	14.7 a	14.5 a
SPAD	CF		40.9 a	46.0 a	49.8 a	54.6 a	54.2 a	56.2 b
	AC		39.7 a	46.1 a	47.8 a	53.2 a	51.9 a	53.1 a
	AC-r		42.2 a	45.2 a	47.2 a	54.1 a	52.6 a	52.6 a

Means followed by different letters are significantly different at $P < 0.05$ based on Tukey's test. AC, Acidulo®compost; AC, AC application; AC-r, AC application with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; CF, chemical fertilizer application (control).

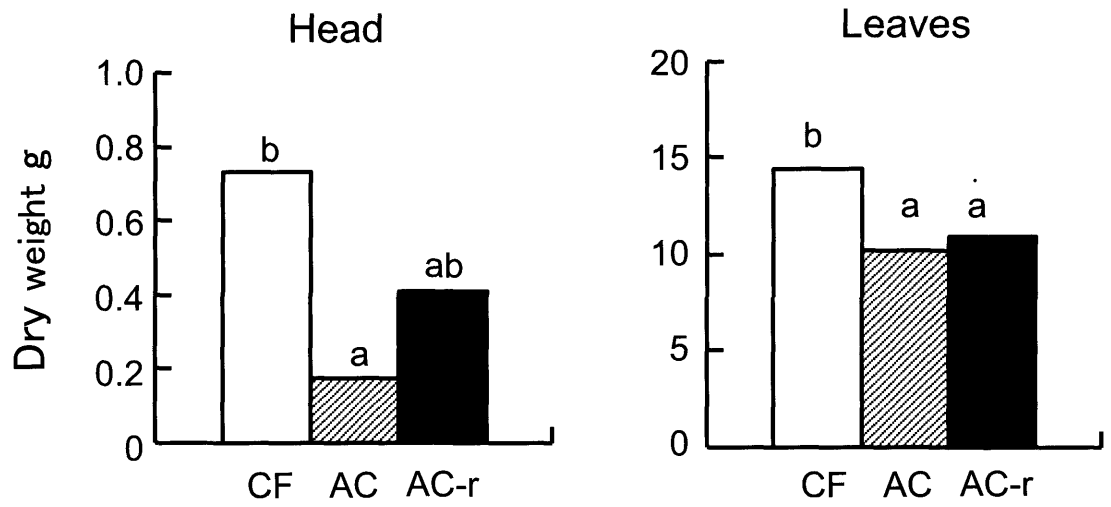

Figure 5. Weights of cabbage heads and leaves in a container experiment (45 days after transplanting) in 2012.

Means followed by different letters are significantly different at $P < 0.05$ based on Tukey's test. AC, Acidulo®compost; AC, AC application; AC-r, AC application with the replacement of the soil in the vicinity of the planting hole with an AC-free soil; CF, chemical fertilizer application (control).

after transplantation onward. The mean weight of cabbage heads was significantly lower in AC (but not in AC-r) than in CF (Figure 5) at 45 days after transplanting. As mentioned above, cabbage yields in the field experiment in 2012 (Table 2) were higher (not significant) when AC was surface-applied (AC-S) than that under other AC applications. These results suggest that it is important to avoid exposing cabbage roots to AC in the initial growth period. In addition to the application method, the dose of AC was also critical in suppressing weed growth while minimizing adverse effects on crop growth (Figure 2 and Table 2). Although there is controversy for applying phytotoxic organic materials to a cultivated field, AC has a potential to be used as an efficient biological weed control method, which can contribute to reduction of herbicide usage. Further studies are necessary to develop a more effective AC application technique that optimizes both the dose and the method of application for cabbage.

Conclusion

AC, a food waste material processed under thermophilic and acidic conditions, has the potential to be used in weed control. During cabbage cultivation, weed emergence was significantly suppressed by AC for 1 month after its application. Because the phytotoxic properties of AC may adversely affect crop yields, methods for the optimal application of AC must be developed. An alternative application method of AC that replaces the AC-amended soil inside planting holes with AC-free soil was effective in partly mitigating adverse effects on the growth of cabbage seedlings. Further studies are necessary to develop an appropriate AC application method that can suppress weed growth effectively without reducing crop yields.

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