Bot. Bull. Acad. Sin. (1993) **34:** 223-234

Allelochemicals in rhizosphere soils of flowering and nonflowering bamboo plants

C. S. Tsai[1] and C. C. Young[2]

[1]*Department of Agronomy, Taiwan Sugar Research Institute, Tainan, Taiwan 701, Republic of China*
[2]*Department of Soil Science, National Chung Hsing University, Taichung, Taiwan 402, Republic of China*

(*Received November 21, 1993; Accepted April 12, 1993*)

Abstract. This research is intended to show the phytotoxic effects of allelochemicals in the rhizosphere soils of flowering and nonflowering bamboo (*Dendrocalamus latiflorus* Munro). Seed bioassay results showed that phytotoxcity was higher in the rhizosphere soils of blooming bamboo plants than in that of nonflowering plants. The amounts of free and bound phenolics in flowering-plant soils were significantly higher than those in nonflowering-plant soils. The following allelochemicals were identified in the rhizosphere soils of flowering bamboo plants: *p*-hydroxybenzoic-, *trans*-*p*-hydroxycinnamic-, *β*-(*m*-hydroxyphenyl)propionic-, *trans*-ferulic-, 3,4-dimethoxyphenylacetic-, *cis*-*p*-hydroxycinnamic-, syringic-, 3,4,5-trimethoxybenzoic-, and 2,6-dihydroxybenzoic acid, and 4-hydroxy-3-methoxybenzaldehyde. The concentration of water-extractable allelochemicals in flowering-plant soil solutions ranged from 2 to 4 μM. In all soils, the amount of each allelochemical that was water-extractable represented only a small portion of the total amount, which was estimated by extraction of the soil with CaO and NaOH. The presence of large amounts of allelochemicals in flowering-plant soils may be the first step in defining the cause-and-effect relationship of flowering. The results indicate that more free phenolics are in the flowering-plant rhizosphere soils which may prove to be significant in explaining the flowering bamboo plant.

Key words: Allelochemicals; Bamboo; *Dendrocalamus latiflorus*; Flowers; Phenolics; Rhizosphere soil.

Introduction

Bamboo (Bambusaceae) is one of the economically important plants in Asia; its many uses in food and manufacturing are well known. *Dendrocalamus latiflorus* Munro is one of the main bamboo and vegetable plants in Taiwan, and the flowering of this species has often been seen in the winter season. The flowering occurs in the whole clump, even in the new shoot culms (less than one year old). The earliest flowering takes place in October and ends in February; however, the flowering period in Taiwan covers about 6 months. After flowering the whole clump will die, and a marked reduction in yield of bamboo occurs in the flowering bamboo plantation. It is normal for an annual plant to die after flowering; however, the death of bamboo after flowering is unusual, because most bamboo plants are long-lived monocarpous ones, being one of natures "century plants" (Numata, 1970).

There are several proposals on the causes of bamboo flowering, including ripeness, simple periodicity, state of nutrition, soil nutrient deficiency, the rhizome system, and damage by insect pests, disease, or drought (Chiang, 1969; Janzen, 1976; Kennard, 1955; Salisbury, 1963; Ueda, 1960; Wang and Chen, 1971), with the latter authors reporting that no correlation between flowering and age or size is found in the flowering of bamboo. Chou and Hou (1981) evaluated the phytotoxic effects of 14 bamboo species and showed that *Sinocalamus latiflorus* had the highest phytotoxicity. Plant flowering can be related to, or controlled by, phenolic substances

(Bernier *et al.*, 1981). Allelochemical compounds could accumulate in the rhizosphere soil of perennial plants, and finally cause flowering. The mechanism of such flowering is still obscure. This research shows the phytotoxic effects of allelochemicals in the rhizosphere

all samples were air dried, crushed, and passed through a 2-mm sieve prior to further analysis. Soil pH was measured using a 1:1 (w/v) soil/water suspension ratio, with a combination glass-calomel electrode. Organic matter and total N in soil

soils of flowering and nonflowering *Dendrocalamus latiflorus* Munro, and how these phenomena are related to flowering.

Materials and Methods

Sampling of Bamboo Soils

Soil samples were collected from bamboo plantations at Tali and Taichung in Taiwan. The bamboo plants had been grown continuously for bamboo shoot

kley and Black (Allison, 1965) and the Kjeldahl procedures (Bremner, 1965), respectively. Particle-size analysis was completed by the pipette method (Soil Survey Staff, 1984). Cation exchange capacity was determined by NH_4^+ saturation (Chapman, 1965). The mineral elements N, P, K, Ca, Mg, Na, Fe, Mn, Cu, and Zn were estimated as described in Methods of Soil Analysis (Page, 1982). Some selected physical and chemical characteristics of the study soils are shown in Table 1.

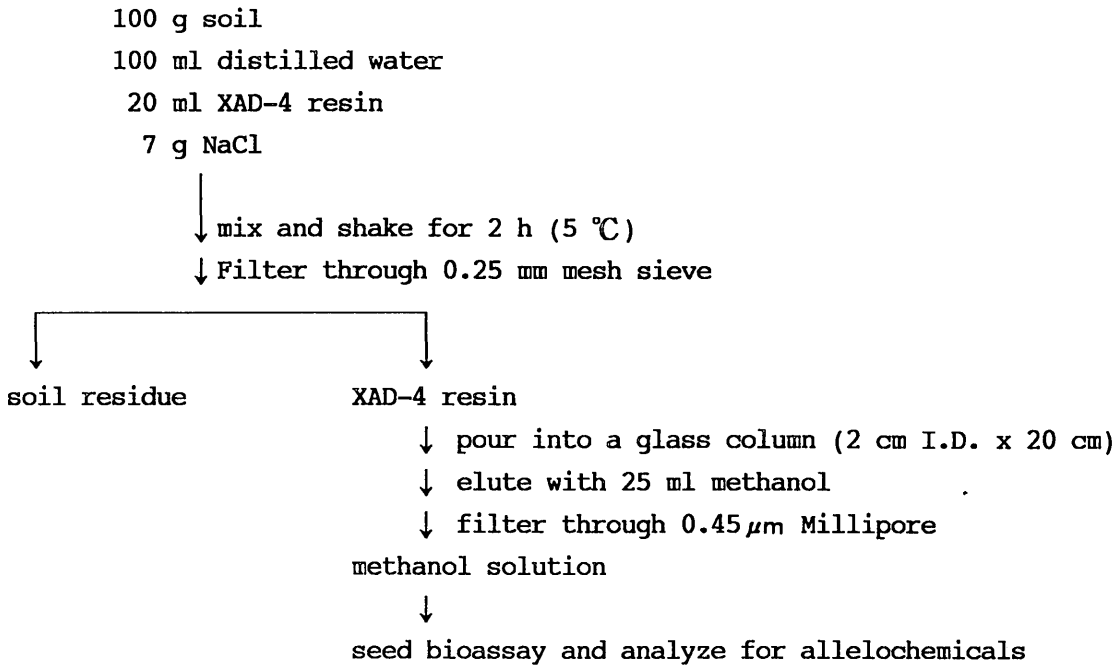

Fig. 1. Soil extraction procedure by using XAD-4 method.

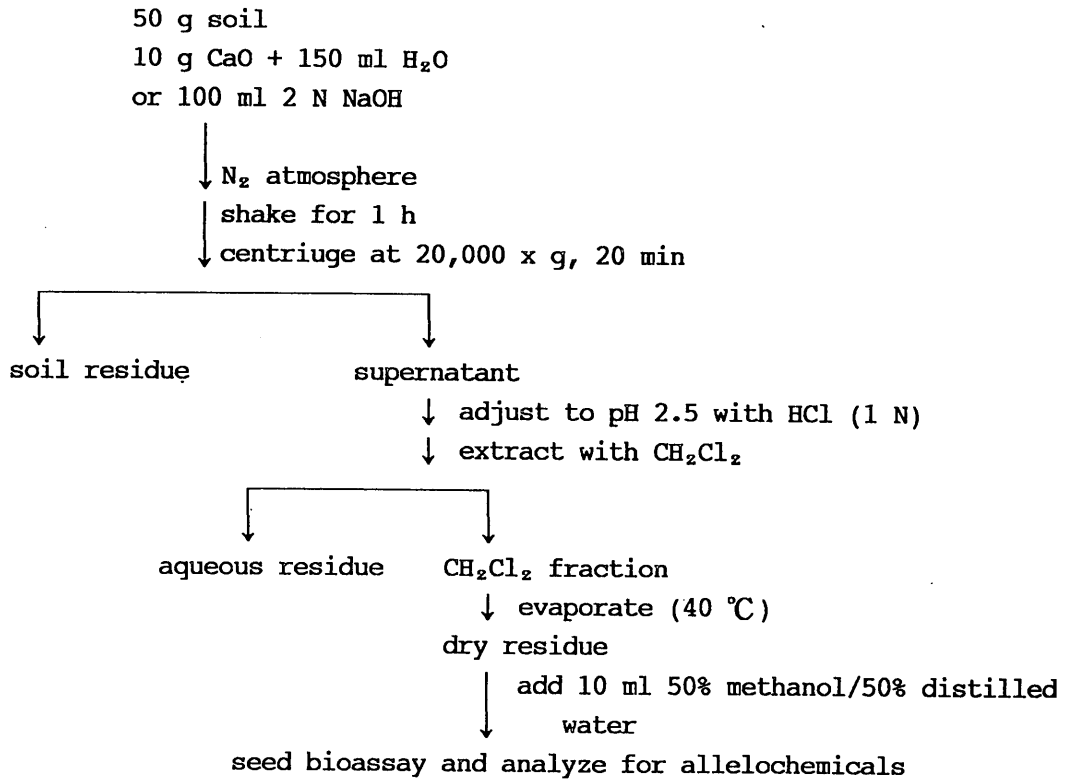

Fig. 2. Soil extraction procedure by using CaO or NaOH extractions.

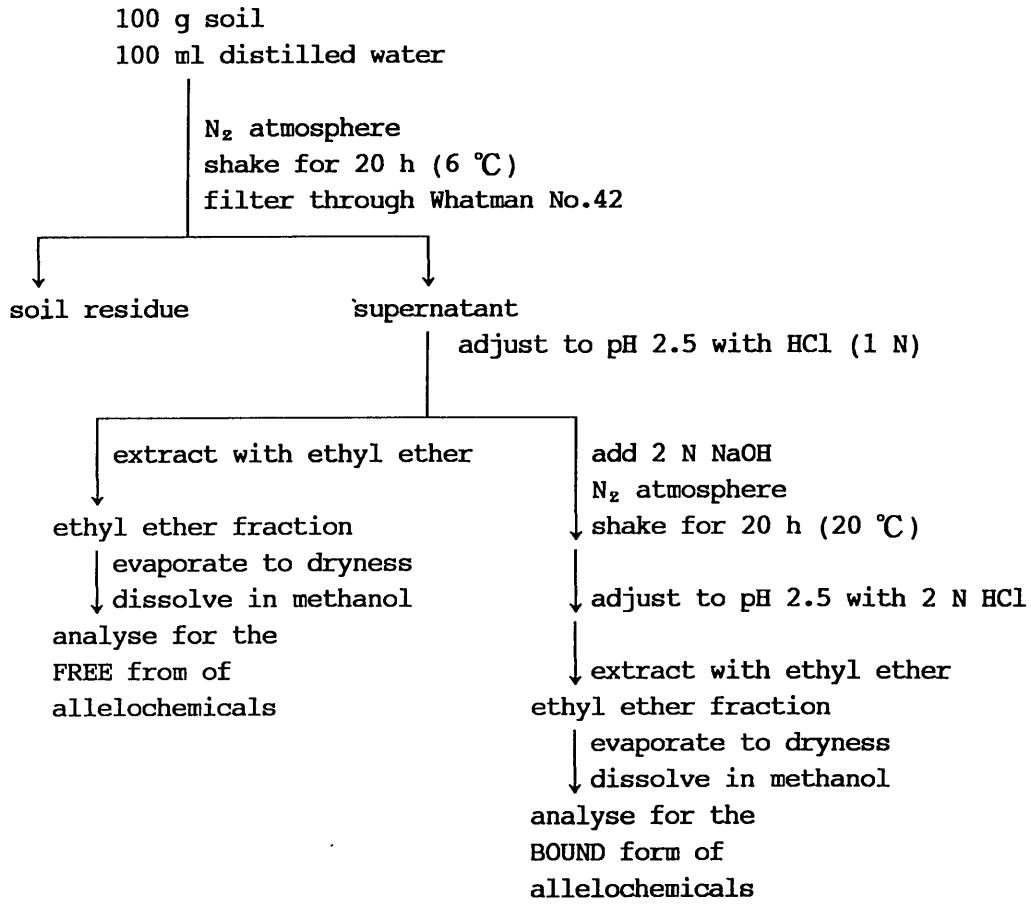

Fig. 3. Soil extraction procedure for free and bound forms of allelochemicals by using water extraction.

ples were collected during the winter season (early December). Soil moisture content ranged from 10% to 33% (Table 1). Any visible plant or root residues were removed, as far as possible, by hand and by passing through a 4-mm sieve. The extraction was performed immediately for analysis of phenolic compounds. The soils were extracted in triplicate and the extracts stored below 5°C until further analysis.

Paper Bioassay

To evaluate the phytotoxic effects of soil extracts

incubation at 28°C the results were taken by measuring the length of radicle growth. The phytotoxicity is calculated as the ratio of radicle growth in the test solution to that in the distilled water control and is expressed as percent inhibition. Differences among the mean values from three replicates of treatment were compared using Duncan's multiple range test.

Identification and Estimation of Allelochemicals in Soil Extracts

The components of soil extracts assumed to be

cromeritics Co., USA) set at 250 and 280 nm. Reversed-phase chromatography was carried out using a steel column (25 cm by 4.6 mm i.d.) containing Nucleosil C_{18} (7 μm) bonded on silica gel (Merchery-Nagel Duren, Germany), and isocratic elution was done with water, acetic acid (ALPS Co., ROC; LC Grade), and n-butanol (Mallinckrodt Co., USA; HPLC Grade) in the proportions 347:1:11, as described by Hartley and Buchan (1979). The flow-rate was 1.0 ml min and the column pressure was 1150 psi. The standard curves of the reference phenolic compounds were linear over the range of 0 to 100 mg kg^{-1}. The extracts from the soils, obtained using various extraction techniques, were subjected to HPLC in triplicate. The unknown compounds were estimated by comparison to the standard curves. Samples and standard solutions were also analyzed by TLC, using cellulose plates developed with 0.33 *M* glacial acetic acid. After developing, the spots were detected under shortwave UV light and the chromatograms were sprayed with DPNA (diazotized *p*-nitroaniline) followed by 0.94 *M* sodium carbonate (Bray *et al.*, 1950).

Results and Discussion

Phytotoxic Effects in Bamboo Rhizosphere Soils

Aqueous soil-extracts obtained by the XAD-4 method were used to analyze the phytotoxic potential of bamboo soils. The phytotoxic effects of rhizosphere and nonrhizosphere soils on bamboo plant from Tali and Taichung are shown in Table 2. Bioassay results showed that the extracts from rhizosphere soils were significantly more phytotoxic than those from nonrhizosphere soils, and that the phytotoxicity of the rhizosphere soils from flowering plants was higher than that from nonflowering plants. This is interpreted to mean that allelochemicals accumulated in the rhizospheres of monoculture bamboo plants. Soils from the Tali bamboo plantation exhibited more potent toxic effects than did soils from the Taichung bamboo plantation.

Identification of Allelochemicals in Rhizosphere Soils of ***Dendrocalamus latiflorus***

Allelochemicals may accumulate in the soil after they are released from the plants. An attempt was made to extract and identify these allelochemicals from the bamboo soils. Preliminary examination by TLC showed the presence of syringic-, *p*-hydroxybenzoic-, *trans*-ferulic-, β-(*m*-hydroxyphenyl)propionic-, and *trans*-*p*-hydroxycinnamic acids, and 4-hydroxy-3-methoxybenzaldehyde in alkaline soil extracts of flowering bamboo plants by their Rf values and their color reactions (Table 3).

An HPLC equipped to measure absorption at two wavelengths (250 and 280 nm) was used to detect the

Table 2. *Allelopathic effects of XAD-4 extracts of the nonrhizosphere soil and rhizosphere soils of* ***Dendrocalamus latiflorus*** *Munro plantations on the growth of lettuce seedlings*

Extract of soil	Solution equilibrated weight of soil (g/mL)	Inhibition of growth over that in distilled water (control) (%)	
		Tali *D. latiflorus* plantation	Taichung *D. latiflorus* plantation
Nonrhizosphere soil	1	30.5a[a]	3.7a
	2	41.5a	13.7b
	4	84.7bcd	37.9c
Rhizosphere soils			
Nonflowering	1	75.1b	47.7d
	2	87.7cde	50.4de
	4	96.4de	87.1f
Flowering	1	81.1bc	57.8e
	2	93.5cde	59.2e
	4	99.5e	90.0f

[a]Means in the same column with the same letter are not significantly different (P=0.05) by Duncan's multiple range test.

phenolic compounds. The results showed that the number of peaks were different for each of the three extraction methods (Table 4). The relative contents of identified allelochemicals in extracts of rhizosphere-soils from the bamboo plantations are shown in Tables 5 and 6. Syringic-, *trans*-*p*-hydroxycinnamic-, 3,4,5-trimethoxybenzoic-, *trans*-ferulic-, *p*-hydroxybenzoic-, 3,4-dimethoxyphenylacetic-, and 2,6-dihydroxybenzoic acids, and 4-hydroxy-3-methoxybenzaldehyde were identified in the rhizosphere soils of flowering bamboo plants (Fig. 4). After hydrolysis with alkaline treatment, *β*-(*m*-hydroxyphenyl)propionic-, *cis*-*p*-hydroxycinnamic-, and 2,6-dimethoxybenzoic acids were detected in the rhizosphere soils of flowering plants from the Taichung and Tali bamboo plantations. Peak identifications were carried out on the basis of retention time of these phenolic compounds (Tsai, 1987).

The HPLC chromatograms for rhizosphere soils from flowering and nonflowering plants were similar (Fig. 4). Some of the phenolic compounds were found in the nonrhizosphere soils, but the relative amounts of allelochemicals were far less than found in the rhizosphere soils of bamboo clumps. The number and height of peaks for different soils followed the sequence: flowering-plant rhizosphere soil > nonflowering-plant rhizosphere soil > nonrhizosphere soil.

The phenolic compounds; such as *p*-hydroxybenzoic-, syringic-, *p*-hydroxycinnamic-, and ferulic acids, that were found in bamboo soils have been recognized as phytotoxins (Borner, 1960; Chou and Muller, 1972; McPherson *et al.*, 1971; Patrick, 1971; Rice, 1979;

Table 3. *Identification of allelochemicals from NaOH alkaline soil extracts of flowering* ***Dendrocalamus latiflorus*** *Munro by thin layer chromatography*

Compound	Rf values[a]	Color[b]		
		UV	DPNA	10% Na_2CO_3
p-Hydroxycinnamic acid	0.52	ab	ND	dk pu
Syringic acid	0.59	ab	or	pu
p-Hydroxybenzoic acid	0.64	ab	ND	r
trans-Ferulic acid	0.38	bl fl	ND	pu bl
Vanillin	0.70	ab	ND	pu bl
β-(*m*-Hydroxyphenyl) propionic acid	0.82	ab	yel	pk

[a]Rf values are averages of three determinations using 2% acetic acid as developing solvent on cellulose plates.
[b]UV = 254 nm, DPNA = diazotized p-nitroaniline, ab = absorption, bl = blue, fl = fluorescence, yel = yellow, dk = dark, pu = purple, r = red, pk = pink, ND = not detectable.

Table 4. *Number of peaks by HPLC analysis of extracts of nonrhizosphere soil and rhizosphere soils of* ***Dendrocalamus latiflorus*** *Munro plantations using three extraction methods*

Location and soil	Number of peaks by HPLC analysis				
		Water-soluble		Alkaline hydrolysis	
	XAD-4	Free-type	Bound-type	CaO	NaOH
Tali *D. latiflorus* plantation					
Nonrhizosphere soil	7 (4)[a]	4(3)	12 (6)	12 (7)	14 (7)
Nonflowering rhizosphere soil	10 (5)	7 (5)	13 (6)	14 (7)	16 (7)
Flowering rhizosphere soil	11 (5)	9 (5)	14 (6)	16 (7)	20 (7)
Taichung *D. latiflorus* plantation					
Nonrhizosphere soil	2 (2)	5 (4)	10(6)	11 (7)	13 (7)
Nonflowering rhizosphere soil	9 (5)	5 (4)	12 (6)	14 (7)	14 (7)
Flowering rhizosphere soil	9 (5)	10 (5)	12 (6)	13 (7)	19 (7)

[a]Number of identified compounds.

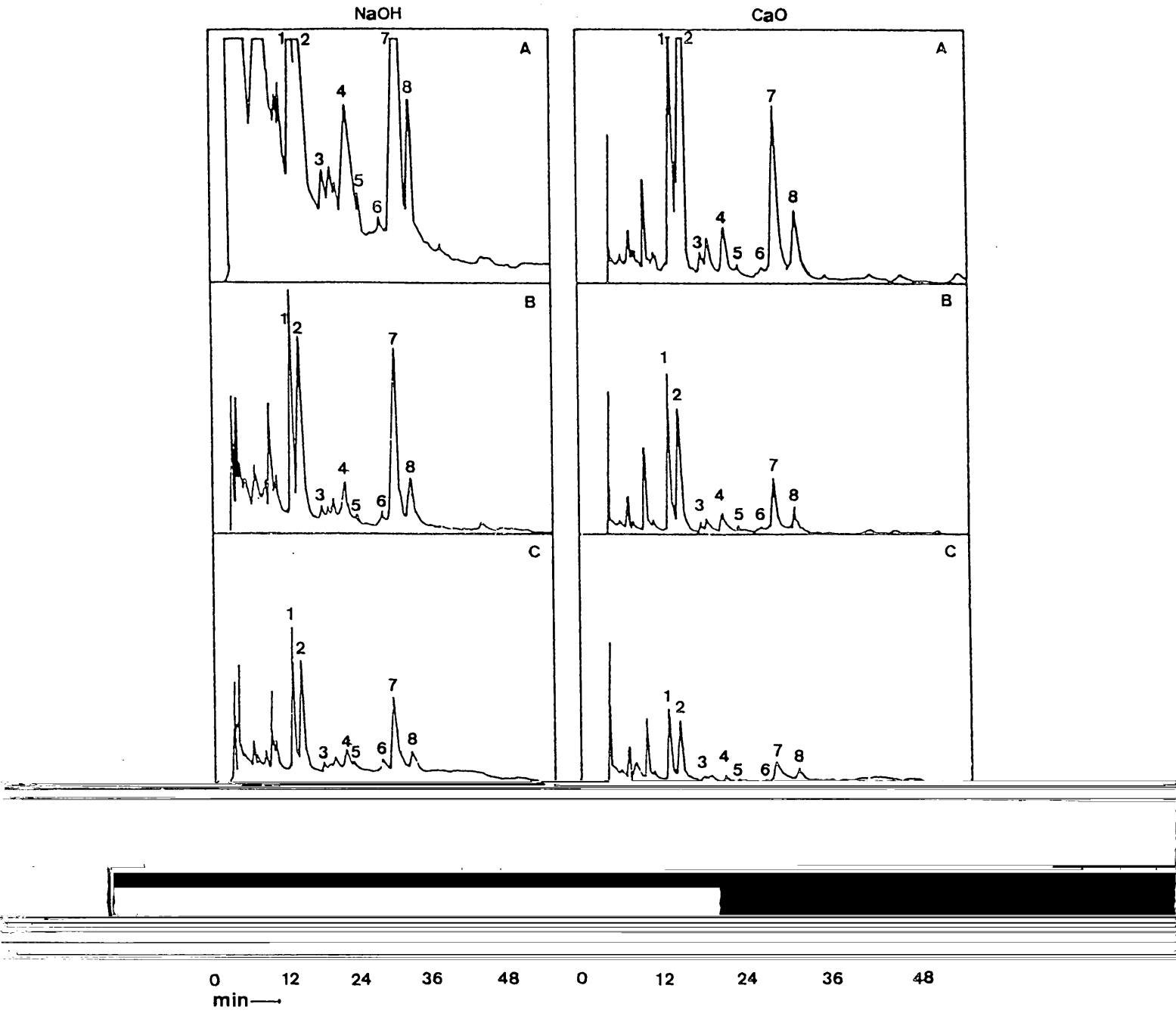

Fig. 4. HPLC Chromatograms of NaOH and CaO extraction from soils of flowering plant (A), nonflowering plant (B) and nonrhizosphere (C). Peaks 1-8 were identified as *p*-pydroxybenzoic acid, syringic acid, vanillin, *β*-(*m*-hydroxyphenyl)propionic acid, *cis*-*p*-coumaric acid, *cis*-ferulic acid, *trans*-*p*-coumaric acid, and *trans*-ferulic acid, respectively.

Wang *et al.*, 1967), and have been found in a variety of plants and soils (Whittaker and Feeny, 1971). The allelochemicals; such as 2,6-dimethoxybenzoic-, 3,4-dihydroxyphenylacetic-, *β*-(*m*-hydroxyphenyl)propionic-, and 2,6-dihydroxybenzoic acids, that have been identified in bamboo soils have also been recognized as phytotoxins in asparagus soils (Young and Chen, 1989). These authors suggested that yield reduction in the continuous cultivation of asparagus is related to the presence of allelopathic substances in asparagus root

Estimate of the Allelochemicals in Rhizosphere Soils of ***Dendrocalamus latiflorus***

The aqueous soil-extracts obtained by XAD-4 adsorption were subjected to HPLC analysis, and the concentrations of some identified phenolic compounds; such as *p*-hydroxybezoic-, *trans*-*p*-hydroxycinnamic-, *β*-(*m*-hydroxyphenyl)propionic-, syringic-, and *trans*-ferulic acids, and 4-hydroxy-3-methoxybenzaldehyde (which are the main phytotoxins shown in Table 5 and

details of the individual concentrations of the allelochemicals identified in aqueous soil-extracts obtained by XAD-4 and water-soluble methods are shown in Table 7. Because these compounds are part of the soil organic matter, comparisons between soils may be best made in terms of μg of phenolic compounds per gram of organic carbon (Whitehead *et al.*, 1983), and the results on this basis are shown in Table 8 for CaO and NaOH extraction methods. In all soils, the amount of each phenolic compound that was water-extractable represented only a small portion of the total estimated by extracting the soils with CaO and NaOH (Table 7 and 8). The results show that the proportion of water-extractable allelochemicals was less than 2.1% and 0.3% of the total amounts extracted by CaO and NaOH, respectively. As shown in Table 7, with concentrations in the range of 2 to 4 μM in flowering-plant soil solutions the allelopathic effects are generally less apparent. The maximum total concentration of the six compounds was equivalent to 4 μM in the soil solution of flowering-plant rhizospheres. At this low concentration, some inhibition of microbial activity is possible

Table 5. *Allelochemicals identified from rhizosphere soil extracts of nonflowering and flowering* ***Dendrocalamus latiflorus*** *Munro in Tali plantation by three extraction methods using HPLC*

			Water-soluble				Alkaline hydrolysis			
	XAD-4		Free-type		Bound-type		CaO		NaOH	
Allelochemicals	NF-RS[a]	F-RS	NF-RS	F-RS	NF-RS	F-RS	NF-RS	F-RS	NF-RS	F-RS
trans-*p*-Hydroxycinnamic acid	+[b]	+	+	+	+	++	++	++++	++++	+++++
p-Hydroxybenzoic acid	+	+	+	+	+	+	++	+++	+++	++++
Syringic acid	+	+	+	+	+	+	++	+++	+++	+++
4-Hydroxy-3-methoxybenzaldehyde	+	+	+	+	+	+	+	++	+	++
trans-Ferulic acid	−	+	+	+	+	+	+	++	+	++
β-(*m*-Hydroxyphenyl)propionic acid	−	−	−	−	+	+	+	++	++	++
3,4,5-Trimethoxybenzoic acid	+	+	−	+	+	+	+	+	+	+
3,4-Dimethoxyphenylacetic acid	−	−	−	−	−	+	+	++	+	+
cis-*p*-Hydroxycinnamic acid	−	−	−	−	+	+	+	+	+	+
2,6-Dihydroxybenzoic acid	−	−	−	−	−	−	−	+	−	+
2,6-Dimethoxybenzoic acid	−	−	−	−	−	−	−	−	−	+

[a]NF-RS=nonflowering rhizosphere soil; F-RS=flowering rhizosphere soil.
[b]HPLC identifications were described in a previous publication (Tsai, 1987), and the allelochemicals amount was based on the peak heighth of the HPLC chromatograms (e.g.,+++++>++++>+++>++>+>-).

Table 6. *Allelochemicals identified from rhizosphere soil extracts of nonflowering and flowering* ***Dendrocalamus latiflorus*** *Munro in Taichung plantation by three extraction methods using HPLC*

			Water-soluble				Alkaline hydrolysis			
	XAD-4		Free-type		Bound-type		CaO		NaOH	
Allelochemicals	NF-RS	F-RS	NF-RS	F-RS	NF-RS	F-RS	NF-RS	F-RS	NF-RS	F-RS
trans-*p*-Hydroxycinnamic acid	+	+	+	+	+	++	+++	++++	++++	+++++
p-Hydroxybenzoic acid	+	+	+	+	+	++	+++	+++	+++	++++
Syringic acid	+	+	+	+	+	++	++	+++	+++	++++
4-Hydroxy-3-methoxybenzaldehyde	+	+	+	+	+	+	+	++	++	+++
trans-Ferulic acid	−	+	−	+	+	+	+	++	++	+++
β-(*m*-Hydroxyphenyl)propionic acid	−	−	−	−	−	+	+	+	+	++
3,4,5-Trimethoxybenzoic acid	−	+	−	+	+	+	+	+	−	+
2,6-Dihydroxybenzoic acid	−	−	−	+	+	+	−	++	+	++
cis-*p*-Hydroxycinnamic acid	−	−	−	−	+	+	+	+	+	+

[a]NF-RS=nonflowering rhizosphere soil; F-RS=flowering rhizosphere soil.
[b]HPLC identifications were described in a previous publication (Tsai, 1987), and the allelochemicals amount was based on the peak heighth of the HPLC chromatograms(e.g.,+++++>++++>+++>++>+>-).

Table 7. *Quantities of water soluble allelochemicals in the soil solution extracted from soils[a] of bamboo plantations with XAD -4 and water extraction methods*

Allelochemicals / Extraction method	Tali plantation			Taichung plantation		
	NRS	NF-RS	F-RS	NRS	NF-RS	F-RS
				nM		
trans-*p*-Hydroxycinnamic acid						
XAD-4	444	365	665	187	378	570
Water (Free-type)	104	73	352	23	54	272
Water (Bound-type)	392	420	489	23	621	272
Syringic acid						
XAD-4	235	256	411	93	351	353
Water (Free-type)	52	110	313	93	189	299
Water (Bound-type)	313	292	254	280	378	706
p-Hydroxybenzoic acid						
XAD-4	209	311	724	93	378	869
Water (Free-type)	78	164	489	93	162	407
Water (Bound-type)	522	585	705	210	351	597
trans-Ferulic acid						
XAD-4	52	110	176	—	162	244
Water (Free-type)	—	73	294	—	54	109
Water (Bound-type)	131	274	196	233	378	407
4-Hydroxy-3-methoxybenzaldehyde						
XAD-4	104	219	274	—	243	272
Water (Free-type)	52	237	333	23	135	136
Water (Bound-type)	183	201	215	163	243	244
cis-*p*-Hydroxycinnamic acid						
Water (Bound-type)	78	73	78	47	81	109
Total[b]						
XAD-4	1045	1260	2251	373	1512	2308
Water (Free-type)	287 (15.1)[c]	658 (26.3)	1781 (49.2)	233 (19.6)	594 (22.4)	1222 (34.4)
Water (Bound-type)	1619 (84.9)	1845 (73.7)	1838 (50.8)	956 (80.4)	2052 (77.6)	2335 (65.6)

[a]NRS=Nonrhizosphere soil; NF-RS=Nonflowering rhizosphere soil; F-RS=Flowering rhizosphere soil.
[b]Total amounts of the six allelochemicals.
[b]Percentage of total water extract.

Table 8. *Quantities of allelochemicals extracted from soils[a] of bamboo plantations with CaO and NaOH extraction methods*

Allelochemicals / Extraction method	Tali plantation			Taichung plantation		
	NRS	NF-RS	F-RS	NRS	NF-RS	F-RS
				$\mu g\ g^{-1}$ organic carbon		
trans-*p*-Hydroxycinnamic acid						
CaO	176	366	912	184	368	702
NaOH	1568	2733	3296	1837	1912	5430
Syringic acid						
CaO	203	297	520	143	237	289
NaOH	595	802	1256	469	351	816
p-Hydroxybenzoic acid						
CaO	54	89	208	20	70	79
NaOH	243	287	416	224	158	368
trans-Ferulic acid						
CaO	68	99	184	41	96	158
NaOH	243	416	528	184	289	710
4-Hydroxy-3-methoxybenzaldehyde						
CaO	27	40	72	20	35	44
NaOH	122	148	192	224	105	237
cis-*p*-Hydroxycinnamic acid						
CaO	7	10	16	6	9	9
NaOH	54	49	72	41	53	53
β-(*m*-hydroxyphenyl)propionic acid						
CaO	95	188	360	163	184	202
NaOH	743	1000	904	1000	544	1175
Total[b]						
CaO	630	1089	2272	577	999	1483
NaOH	3568	5435	6664	3959	3412	8789

[a]NRS=Nonrhizosphere soil; NF-RS=Nonflowering rhizosphere soil; F-RS=Flowering rhizosphere soil.
[b]Total amounts of the seven allelochemicals.

(Rice and Pancholy, 1974), although inhibition of plant growth appears unlikely (Chou nd Patrick, 1976). However, it is apparent that the total amount of allelochemicals identified and calculated in the soil extracts of flowering-plant rhizospheres was significantly larger than that in the soil-extracts of nonflowering-plant rhizospheres and of nonrhizosphere soil.

It is extremely difficult to estimate the actual concentrations of allelochemicals in the soil because of the uncertainties about the effects of dynamic alterations

cause-and effect relationship.

Dendrocalamus latiflorus Munro is the most widespread bamboo in Taiwan and is famous for sporadic flowering. Clumps of flowering bamboo are often found beside a ditch or drain, and the soils at the site are usually imperfectly or poorly drained. This phenomenon has been recorded in field observations (Wang and Chen, 1971), but the reason was little understood or discussed. Under poor water drainage, the quantities of phytotoxic substances are significantly higher those

the field. As discussed by Whitehead *et al.* (1981), phenolics would not be uniformly distributed in undisturbed soil, and localized concentrations close to fragments of decomposing plant material might be sufficiently high to produce some effects. Rice (1979) considers that some compounds may influence plant growth at concentrations at which they are completely adsorbed by soil particles and are not extractable by

greater phytotoxicity (Chou, 1987). Furthermore, Wu *et al.* (1976) found that the total amount of phytotoxic phenolics in the well-drained Tsaotun soil (52 mmol kg^{-1} soil) was significantly lower than that in the poorly drained Lotung soil (192 mmol kg^{-1} soil). They also reported that the amounts of non-volatile and volatile fatty acids were significantly lower in the well-drained soil (76 μmol kg^{-1} soil) than those in the poorly drained

Chapman, H.D. 1965. Cation-Exchange Capacity. *In* C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger and F. E. Clark (eds.), Methods of Soil Analysis. Part 2. Agron. Monogr. 9. Amer. Soc. Agron. Madison, WI., pp. 894-895.

Chiang, T. 1969. Physiology of bamboo flowering. Tech. Bull., Exp. For. Nat. Taiwan Univ. **85:** 1-4.

Chou, C. H. 1987. Allelopathy in subtropical vegetation and soils in Taiwan. *In* G. R. Waller (ed.), Allelochemicals: Role in agriculture and forestry. ACS, Washington, DC. pp. 102-117.

Chou, C. H. and M. H. Hou. 1981. Allelopathic researches of subtropical vegetations in Taiwan. I. Evaluation of allelopathic potential of bamboo vegetation. Proc. Nat. Sci. Council. Part B, **5:** 284-292.

Chou, C. H. and C. H. Muller. 1972. Allelopathic mechanisms of *Arctostaphylos glandulosa* var. *zacaensis*. Am. Midl. Natur. **88:** 324-347.

Chou, C. H. and Z. A. Patrick. 1976. Identification and phytotoxic activity of compounds produced during decomposition of corn and rye residues in soil. J. Chem. Ecol. **2:** 369-387.

Hartley, R. D. and H. Buchan. 1979. High-performance liquid chromatography of phenolic acids and aldehydes derived from plants or from the decomposition of organic matter in soil. J. Chromatogr. **180:** 139-143.

Janzen, D. H. 1976. Why bamboos wait so long to flower. Ann. Rev. Ecol. Syst. **7:** 347-391.

Kennard, W. 1955. Flowering of the bamboo *Guadua amplexifolia* in Puerto Rico. Lloydia **18:** 4.

McPherson, J. K., C. H. Chou, and C. H. Muller. 1971. Allelopathic constituents of the chaparral shrub *Adenostama fasciaulatum*. Phytochem. **10:** 2925-2933.

Numata, M. 1970. Conservational implications of bamboo flowering and death in Japan. Biol. Conserv. **2:** 227-229.

Page, A. L. 1982. Methods of soil analysis. Part 2. Chemical and Microbiological Properties, 2nd ed., American Society of Agronomy, Madison.

Patrick, Z. A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. **111:** 13-18.

Rice, E. L. 1979. Allelopathy-an update. Bot. Rev. **45:** 15-109.

Rice, E. L. and S. K. Pancholy. 1974. Inhibition of nitrification by climax ecosystem. III. Inhibitors other than tannis. Amer. J. Bot.

Salisbury, F. B. 1963. The flowering process. MacMillan, New York.

Sheh, C. S. and M. K. Wang. 1989. Soils of Taiwan. Soil Survey and Experimental Center, National Chung Hsing University. Taichung, Taiwan. pp. 161-203.

Sparling, G. P., B. G. Ord, and D. Vaughan. 1981. Changes in microbial biomass and activity in soils amended with phenolic acids. Soil Biol. Biochem. **13:** 455-460.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigation. Rep. no. 1. Revised (ed.), USDA-Soil Conservation Service. U. S. Gov. Print. Office, Washington, DC.

Soil Survey Staff. 1990. Keys to soil taxonomy. 4th (ed.), Soil Management Support Services Tech. Monogr. no. 6. Blacksburg, Virginia.

Tai, C. S., S. Uemoto, Y. Shoyama, and I. Nishioka. 1981. Biologically active phenolics from *Lilium longiflorum*. Phytochemistry **20:** 2565-2568.

Tsai, C. S. 1987. Studies on phenolic compounds in soils and plant tissues of the flowering and nonflowering *Dendrocalamus latiflorus* Munro plants. M. S. thesis, Dep. Soil Sci., Nat. Chung Hsing Univ., Taiwan. p. 97.

Ueda, K. 1960. Studies on the physiology of bamboos. Bull. Kyoto Univ. For. **30:** 167.

Wang, T. T. and M. Y. Chen. 1971. Studies on bamboo flowering in Taiwan. Tech. Bull. Nat. Taiwan Univ. Exp. For. **87:** 1-25.

Wang, T. S. C., T. K. Yang, and T. T. Chuang. 1967. Soil phenolic acids as plant growth inhibitors. Soil Sci. **103:** 239-246.

Whitehead, D. C., H. Dibb, and R. D. Hartley. 1983. Bound phenolic compounds in water extracts of soils, plant roots and leaf litter. Soil Biol. Biochem. **15:** 133-136.

Whittaker, R. H. and P. P. Feeny. 1971. Allelochemicals: chemical interactions between species. Science **171:** 757-770.

Whitehead, D. C., H. Dibb, and R. D. Havtley. 1981. Extractant pH and the release of phenolic compounds from soil, plant roots and leaf litter. Soil Biol. Biochem. **13:** 343-348.

Wu, M. M. H., C. L. Liu, C. C. Chao, S. W. Shieh, and M. S. Lin. 1976. Microbiological and biochemical studies on the causes of low yielding in the second crop of rice. J. Agric. Assoc. China, Taipei. **96:** 36-37.

Young, C. C. 1984a. Non-polar macroreticular resin to recover phenolic acids from a subtropical latosol. Soil Biol. Biochem. **16:** 377-380.

Young, C. C. 1984b. Autointoxication in root exudates of *Asparagus officinalis* L. Plant Soil **82:** 247-253.

Young, C. C. and S. H. Chen. 1989. Continuous cultivation of *Asparagus* and the allelopathic effect. Tech. Bull. Food & Fert. Tech. Center for the Asian and Pacific Region **116:** 1-8.

蔴竹開花及未開花植物根圈土的相剋毒物質

蔡正勝[1] 楊秋忠[2]

[1]台灣糖業研究所農藝學系
[2]國立中興大學土壤研究所

本研究是爲瞭解開花及未開花蔴竹植物根圈土的毒物質效應。在種子分析結果顯示開花植物的根圈土含有的植物毒性較未開花的爲高，植物相剋物質均存在開花及未開花的蔴竹根圈土中，但游離及附著之酚類在開花植物之根圈土中含量較未開花的爲高，在開花植物的根圈土中鑑定出的植物相剋物質包括*p*-hydroxybenzoic-, *trans*-*p*-hydroxycinnamic-, *β*-(*m*-hydroxyphenyl)propionic-, *trans*-ferulic-, 3,4-dimethoxyphenylacetic-, *cis*-*p*-hydroxycinnamic-, syringic-, 3,4,5-trimethoxybenzoic-, 2,6-dihydroxybenzoic acids 及 4-hydroxy-3-methoxybenzaldehyde。在開花植物的土壤溶液中，水可抽出相剋物質達 2 至 4 μM。在所有測試的土壤中，可用水抽出的相剋物質量均爲 CaO 及 NaOH 萃取總量的少部份。在開花植物的土壤中存有多量相剋物質之發現也許是確定開花原因與作用關係的第一步。本研究結果顯示開花植物根圈土含有較多量之酚類物質，將可能有利証明解釋開花現象。