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IMPACTS OF WATER POLLUTION ON CROP GROWTH IN TAIWAN

V. The Detrimental Effects of Industrial Waste Waters from Dye, Livestock, Plating, Leather, Synthetic-fiber, Food, and Fertilizer Factories in Taiwan(1)

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Abstract

Waste waters coming from eight factories, namely Ching-mei (dye), Chia-shin (livestock), Ta-tung (plating), Lian-ta (leather), Hwa-lung (synthetic fiber), Kuan-chun (food), Tai-fei (fertilizer), and Tai-sen (dye) were determined for their phytotoxicities and physicochemical properties. The effect of the waters on the growth and yield components of rice (*Oryza sativa* Tainan 5) was also undertaken in pots. The bioassay results clearly showed that the waste waters exhibited significant phytotoxic effects on the radicle growth of rice and lettuce. Lettuce was the most sensitive plant to waste water and rice the least. The phytotoxicity varied with industrial waste water, and the order of toxicity was Chia-shin≧Tai-fei>Tai-sen>Kuan-chun>Hwa-lung>Ta-tung>Lian-ta>Ching-mei. The inhibition was not correlated with sampling times either monthly or daily. Most of the test waters significantly retarded the vegetative and reproductive growth of rice plants grown in pots. The suppression of yield and yield components of rice plants was obvious in the second crop, resulting in decrease in panicle numbers, ripening rate, testing weight, and grain yield especially by the original waste water without dilution. The order of this suppression was only slightly different from that of the phytotoxicity test. The physicochemical analyses of these eight industrial waste waters revealed that the values were often above the limits of the standard for irrigation water for agricultural land, and some of these properties, such as electrical conductivity, pH, and contents of suspended solids, Cl^-, SO_4^{-2}, NH_4^+-N, Na and heavy metals of Zn and Cr were the major detrimental factors. The amount of each factor mentioned was well correlated with the phytotoxicity of each waste water.

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Introduction

Due to the rapid economic and industrial development in Taiwan in the last decade, the environmental impact has become a severe problem. Many agricultural lands in Taiwan and particularly the rice paddy fields have been polluted by water coming from adjacent factories. The total area of polluted rice fields has increased from year to year extending from northern Taiwan to the south. An island-wide assessment of the impact of the industrial waste waters on crop growth has been undertaken in the last few years. Recent publications dealing with this study have been reported (Chen, 1973; Chou, 1976; Chou *et al.*, 1978; 1979; 1980; Yang, 1976) and other findings concerning the detrimental effects of polluted waters have been reported by various scientists from many parts of the world (Harada, 1968; Hosornava, 1961; Hung *et al.*, 1961; Hung *et al.*, 1975; WQS, 1969). Since 1977, under the auspices of CAPD, the present authors have studied the Hsinchu and Taoyuan areas, where vast agricultural area was jeopardized by polluted water. We have focused our attention on this area and selected eight major factories in this area to assess the physicochemical nature of their waste waters and to elucidate the phytotoxic mechanisms of the polluted water. As a result of the whole study, we were able to make conclusions and recommendation to relevant agencies to reduce or prevent further damage from polluted waters on crop growth.

Materials and Methods

Sampling and preparation of waste water

Seven major kinds of industrial factories around Hsinchu and Taoyuan areas were selected for this study, these were: dye (Ching-mei and Tai-sen), livestock (Chia-shin), plating (Ta-tung), leather (Lian-ta), synthetic fiber (Hwa-lung), food (Kuan-chun), and fertilizer (Tai-fei) factories. To obtain as much information as possible concerning the fluctuation of the waste waters coming from the aforementioned factories, monthly sampling and six samplings within a day were conducted. The sampling was done on the following dates February 27–28, March 14–15, April 16–18, May 10–11, May 23–24, May 28, June 25, July 26, August 13, September 11–12, September 25–26, October 16–17, October 22–23, and November 28, 1979. The samples were brought back to the laboratory of the Institute of Botany, Academia Sinica, and Taiwan Water Pollution Control Agency, Taipei, and then were immediately filtered through Whatman 3MM filter paper, and stored in a cold room (4°C) before assaying.

Pot experiment setting

This experiment was conducted in the Taiwan Provincial Hsinchu District

Agricultural Improvement Station. About 10 kg soil collected from the Hsinchu experimental farm was placed in each pot (1/2000 are size). Each treatment was set up by using a split design with 4 replicates. Each pot was filled with different waste water with 5-fold (5×) and 10-fold (10×) dilutions. The control experiment was also set up in the same manner but with tap water instead of waste water. Three seedlings of rice variety Tainan 5 were transplanted on March 1, 1979 for the first crop and on August 8, 1979 for the second crop, while the harvest was made on August 30, 1979 and January 20 of 1980, respectively. During the growth period of the rice plants, the length of the rice seedlings and number of tillers were determined on the 20th, 40th, 60th, 80th, 100th, and 120th after transplanting. At the harvest time, the number of panicles, test weight (grain weight/1000 seeds) ripening rate, yield (kg/ha) and the yield index were measured and compared with those receiving other treatments.

Phytotoxicity determination of waste waters

In order to determine the phytotoxicity present in the industrial waste waters, three bioassay techniques were used as described by Chou and Muller (1972) and Chou and Lin (1976). Each water was bioassayed against 3 test species, namely rice (*Oryza sativa* Taichung 65), lettuce (*Lactuca sativa* var. Great Lakes 366), and rye grass (*Lolium multiflorum*). Distilled water served as a control for the bioassay tests. Each bioassay was set up in triplicate, and incubated at 25°C for 72 hr. After incubation, the radicle length of the test plants was measured in millimeters and the phytotoxicity was computed from a formula as follows:

$$\% \text{ Phytotoxicity} = \frac{\text{Radicle length of control—radicle lenght of test}}{\text{Radicle length of control}} \times 100\%$$

then, the negative values expressed the stimulation effect.

The third bioassay technique described by Chou and Lin (1975) was used to determine the effect of industrial waste water on the root initiation of mung beans. This bioassay was set up in the same manner and the % phytotoxicity was obtained by measuring the number of roots initiated after 6 days incubation at 25°C.

Physicochemical analysis of waters

Each aforementioned sample was analyzed for its pH value (Chemtrix type 40 pH meter), and osmotic concentration (Fiske G-66 osmometer). The cation contents present in each water sample were determined by an atomic absorption spectrophotometer (Perkin-Elmer Model 300). These determinations were done in the Plant Ecology Laboratory, Institute of Botany, Academia Sinica. In addition, electrical conductivity (Conductimeter, Tacussel CO-6N), total solids, suspended solids, and contents of chloride, sulfate (Spectrophotometer, Perkin-Elmer 100), and NH_4^+-N were determined by standard methods for the examination of water and waste water (APHA, 1976) and were carried out in the laboratory of the Taiwan Water Pollution Control Agency.

Results

Phytotoxicity of industrial waste waters

Eight industrial waste water collected monthly (from February to November, 1979) were bioassayed on rice and lettuce seeds. Results expressed as percent phytotoxicity on the radicle growth of these seeds are shown in Fig. 1. In the results of Chia-shin water, the phytotoxicities of these plants exhibited 100% in all water collected monthly. The Ching-mei water generally revealed a relatively low phytotoxicity on both plants, except the November water collected. There were relatively low phytotoxicity shown by the Lian-ta waters although the February and November collected waters exhibited significantly high inhibition by lettuce bioassay. In the Ta-tung waste water, the inhibitions revealed from February, April, May, June, August, October, and November of 1979 were significantly higher than the rest. The results of the above four industrial waste waters agreed with those of water collected in 1978.

On the other hand, the waste waters from factories of fertilizer (Tai-fei) and dye (Tai-sen) showed almost 100% inhibition on the radicle growth of both plants, whereas the Hwa-lung water revealed significantly higher phytotoxicity by lettuce than rice plant. The Kuan-chun waste water was shown rather high phytotoxicity by lettuce bioassay.

Furthermore, in order to understand how the phytotoxicity varied with time of 24 hr, six-sampling during a day were made and the results of the bioassay using rice and lettuce as test materials are shown in Fig. 2. It was found that the Tai-fei water revealed 100% inhibition on both rice and lettuce growth regardless of sampling time. The water of Tai-sen also showed significant phytotoxicity except the May sampling, where the inhibition was particularly noticeable in the nighttime sampling than daytime. The Hwa-lung and Kuan-chun waste waters reflected irregular phytotoxicity by rice bioassay and was shown to have inhibition above 50% by lettuce bioassay, where the phytotoxicity was rather stable during a day sampling. It is concluded, based on eight months of sampling that the phytotoxicity in general varied with the sampling times is likely to be irregular; however the order of phytotoxicity is Chia-Shin≧Tai-fei>Tai-sen>Kuan-chun>Hwa-lung>Ta-tung>Lian-ta>Ching-mei. In addition, the toxicity was found to be generally higher in the day time than in the evening, but there was no definite

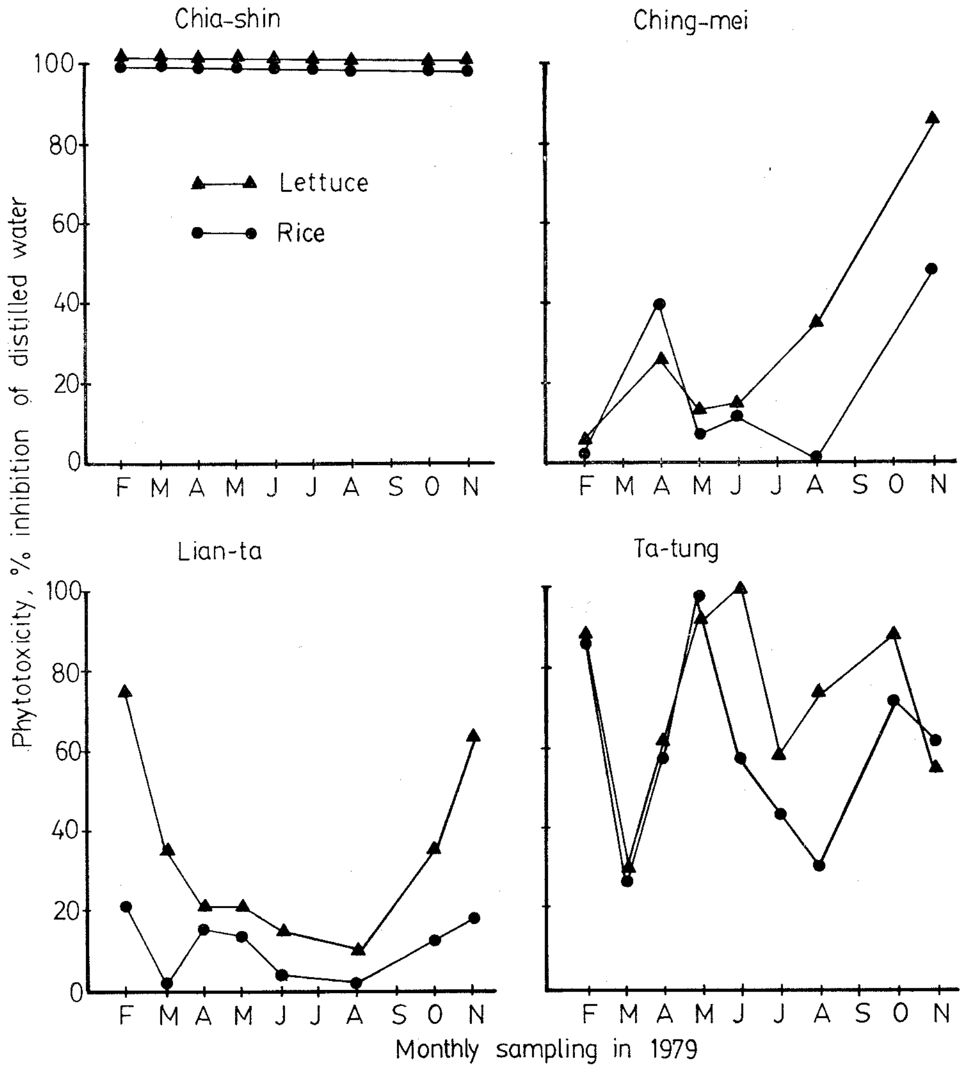

Fig. 1A

Fig. 1A and 1B. The monthly phytotoxic effects of industrial waste water from 8 factories, namely Chia-shih, Ching-mei, Lian-ta, Ta-tung, Hwa-lung, Kuan-chun, Tai-fei and Tai-sen on the radicle growth of lettuce and rice plants. The phytotoxicities were expressed as % inhibition of radicle growth over distilled water control.

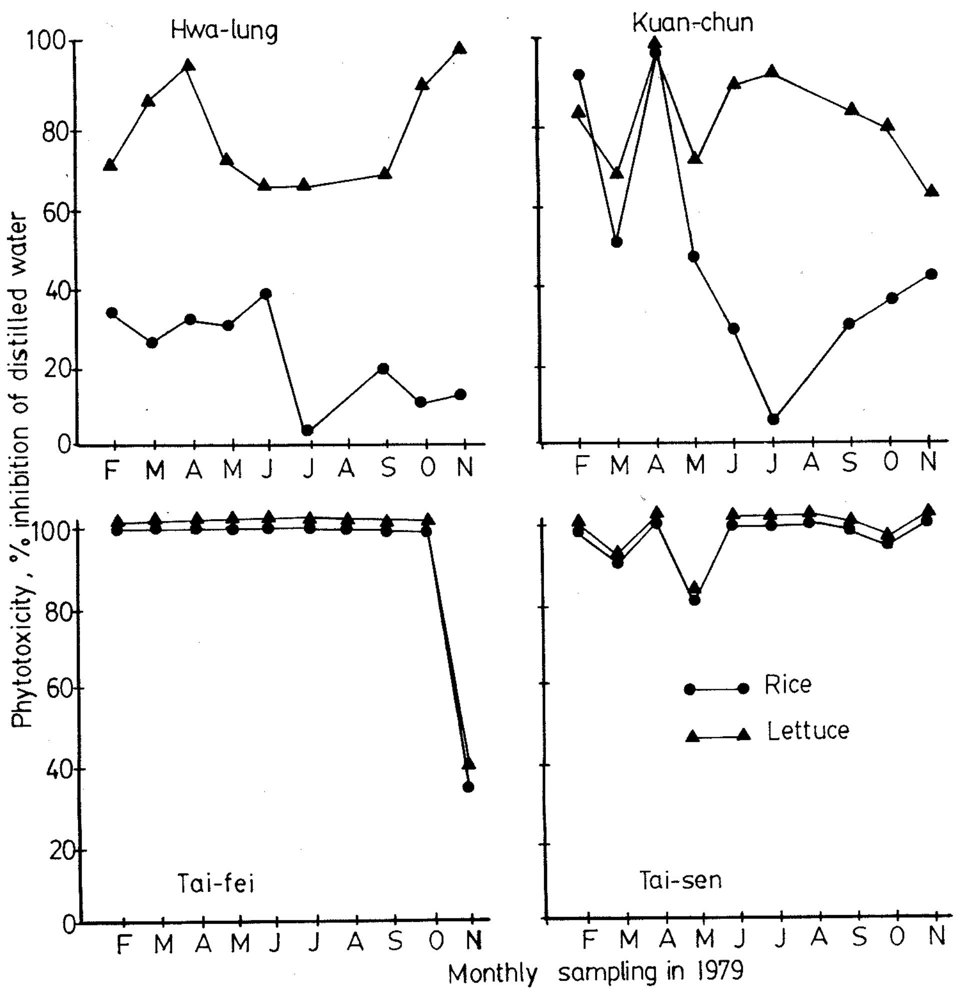
Hwa-lung
Kuan-chun
Tai-fei
Tai-sen
Phytotoxicity, % inhibition of distilled water
100
80
60
40
20
0
F M A M J J A S O N
Rice
Lettuce
Monthly sampling in 1979

Fig. 1B

pattern of phytotoxicity distribution during the sampling times.

Effects of industrial waste waters on rice growth in pots

Eight industrial waste waters, namely Hwa-lung (HL), Kuan-chun (KC), Tai-fei (TF), Tai-sen (TS), Ching-mei (CM), Chia-shin (CS), Lian-ta (LT) and Ta-tung (TT), were used to irrigate rice plants grown in pots. The growth and yield components of rice plants as affected by these waters were examined in both the first and second crop. Although rice plants were measured at the 20th, 40th, 60th, 80th, 100th, and 120th day after transplanting, only the data at 80th and 120th day were represented for comparision. The data were expressed as either % stimulation or % inhibition of rice growth in each industrial water comparing with that in the tap water control. Regarding the plant height of rice affected by industrial waste waters, the Hwa-lung, Chia-shin, and Ta-tung water revealed no significant effect on rice growth in both two crop seasons, whereas the rest waters without dilution exhibtied significant inhibition in the second crop season (Fig. 3A). The inhibition of rice straw length decreased with a series of dilution; where at the 10× dilution the inhibition was rapidly disappeared.

On the other hand, the tiller number of rice plant was also significantly reduced by the waters, namely Kuan-chun, Tai-fei, Tai-sen, Ching-mei, and Lian-ta. This reduction was very pronounced in the original waste water without dilution; however, the inhibtion was sharply decreased with dilution time (Fig. 3B). In addition, the inhibition of tiller number affected by the waste water was significantly higher in the second crop than the first crop (Fig. 3B). As far as the yield components of rice plant were concerned, the inhibition pattern was correlated with that of rice growth. The inhibition of panicle numbers, testing weight, ripening rate and yield of rice plants as affected by the waste waters, except Hwa-lung, was significantly higher in the original water than in the water with 5× and 10× dilution, and was particularly pronounced in the second crop (Fig. 3C, E, and F.). We can not explain why these industrial waste waters significantly suppressed growth and yield of the second crop, but apparently did not affect the first crop. This findings were also found in those of 1977 and 1978.

It is concluded that industrial waste waters except the Hwa-lung water as mentioned above significantly affect the growth and yield of the second crop of rice plants, but have a variable effect on the first crop. The original waste waters from these factories exhibited tremendously toxic effect on rice growth and yield; however, when the water diluted the inhibition decreased.

Physicochemical properties of industrial waste water

Since most of the aforementioned eight factories released waste water

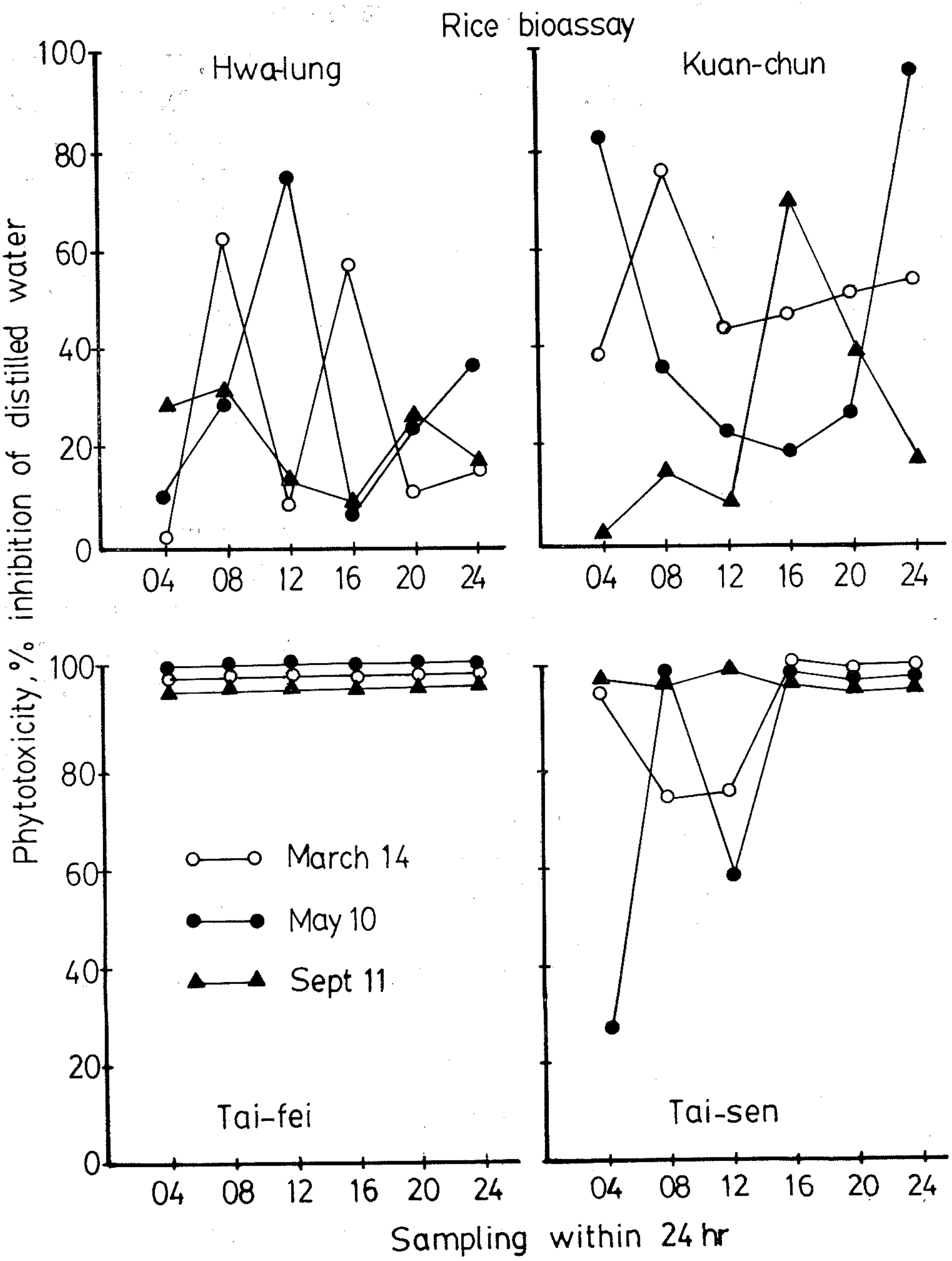

Fig. 2A

Fig. 2. The daily phytotoxic effects of 4 industrial waste waters on the radicle growth of rice and lettuce. For the rest of the description see Fig. 1.

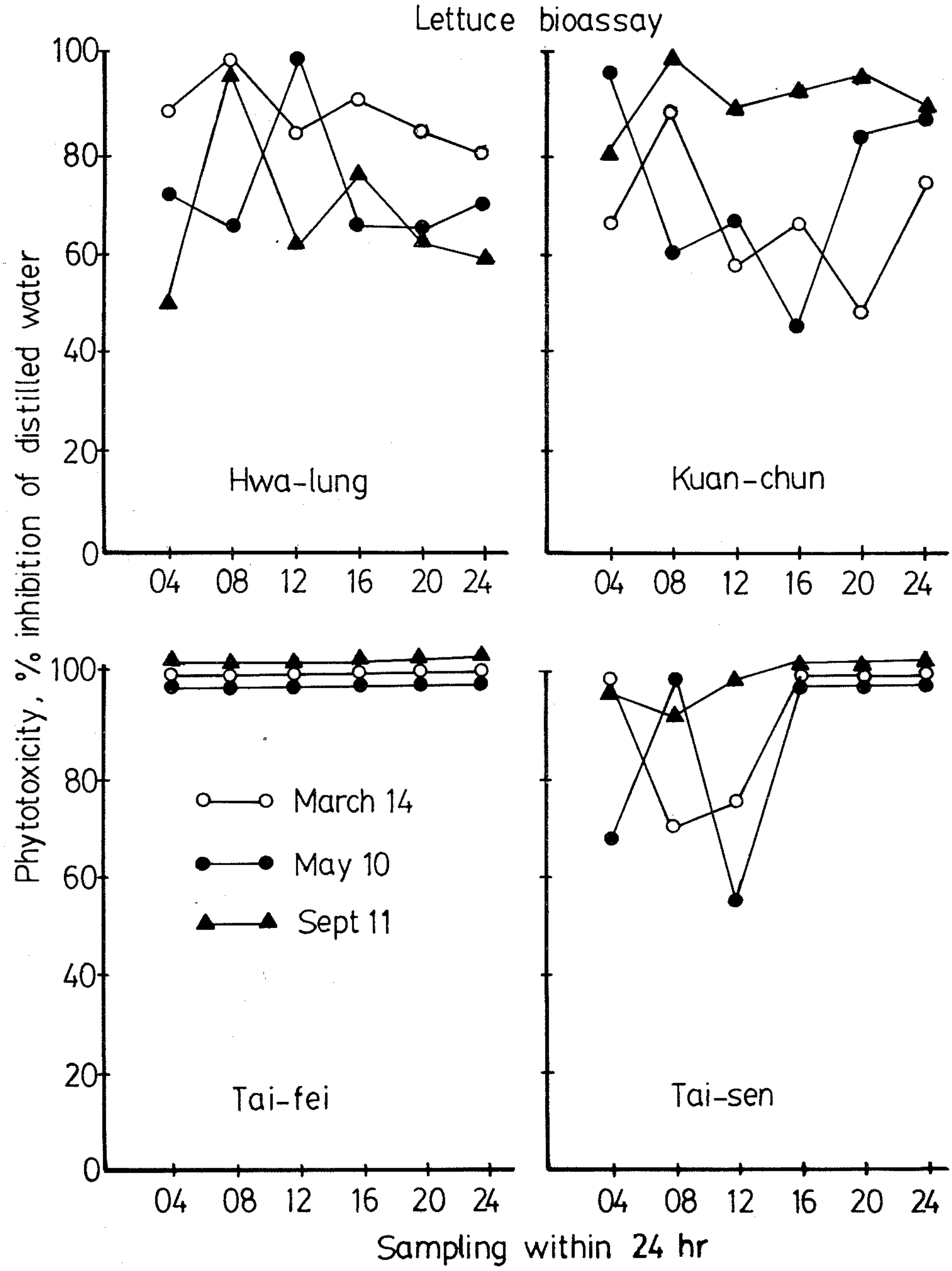
Lettuce bioassay
Phytotoxicity, % inhibition of distilled water
100
80
60
40
20
0
Hwa-lung
Kuan-chun
Tai-fei
Tai-sen
04 08 12 16 20 24
March 14
May 10
Sept 11
Sampling within 24 hr

Fig. 2B

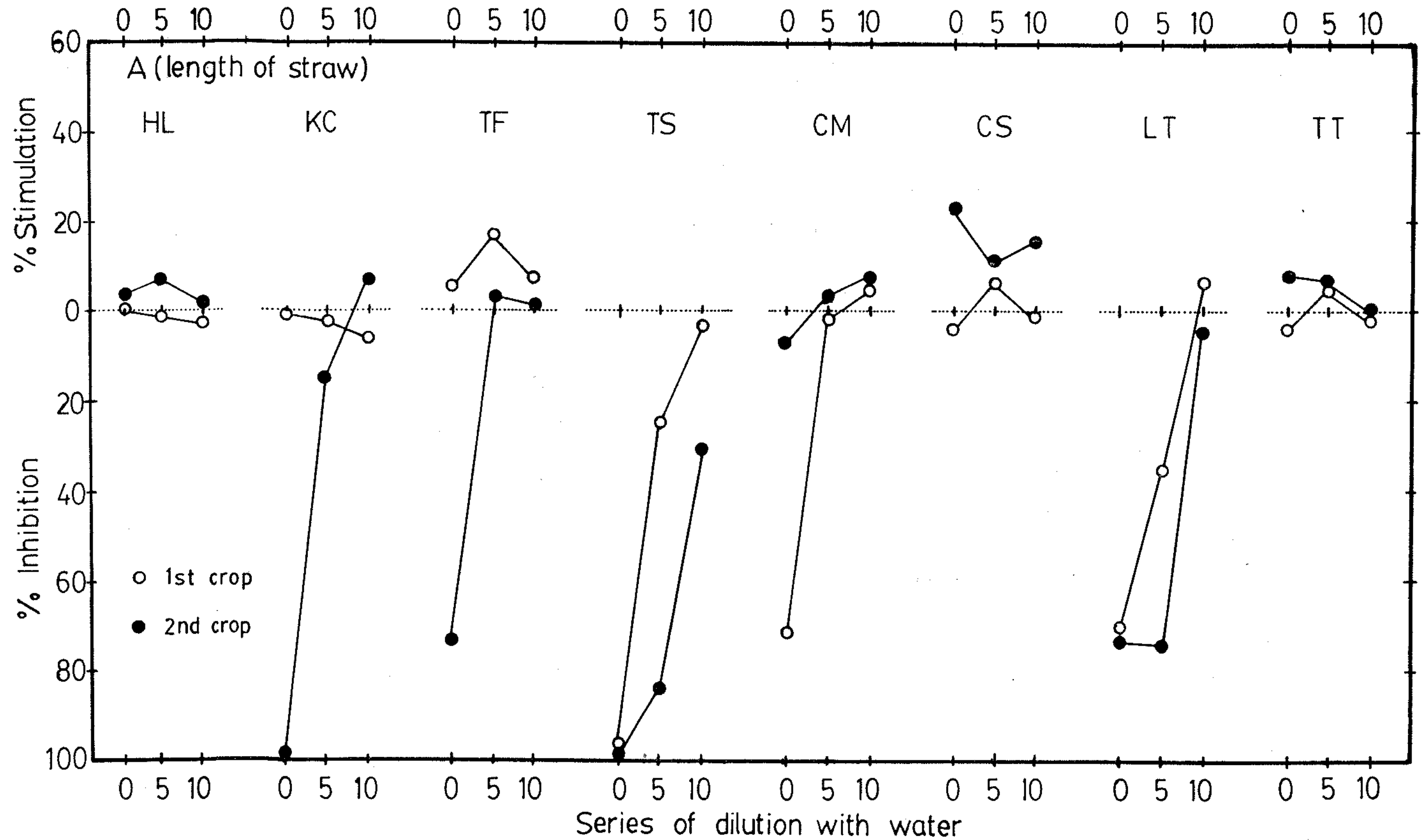

Fig. 3A

Fig. 3. A-F. Comparative effects of 8 industrial waste waters on the growth and yield components of rice plants grown in pots in two crop seasons. The data were expressed as % stimulation or % inhibition of each measurement on that of tap water as control. The eight factories are HL (Hwa-lung), KC (Kuan-chun), TF (Tai-fei), TS (Tai-sen), CM (Ching-mei), CS (Chia-shin), LT (Lian-ta), and TT (Ta-tung). A=Effect on length of rice straw. B=Effect on tiller numbers. C=Effect on panicle numbers. D=Effect on testing weight. E=Effect on ripening rate. F=Effect on yield.
The dilutions are 0 (original waste water without dilution), 5 (dilution with 5 times of tap water), and 10 (dilution with 10 times of tap water).

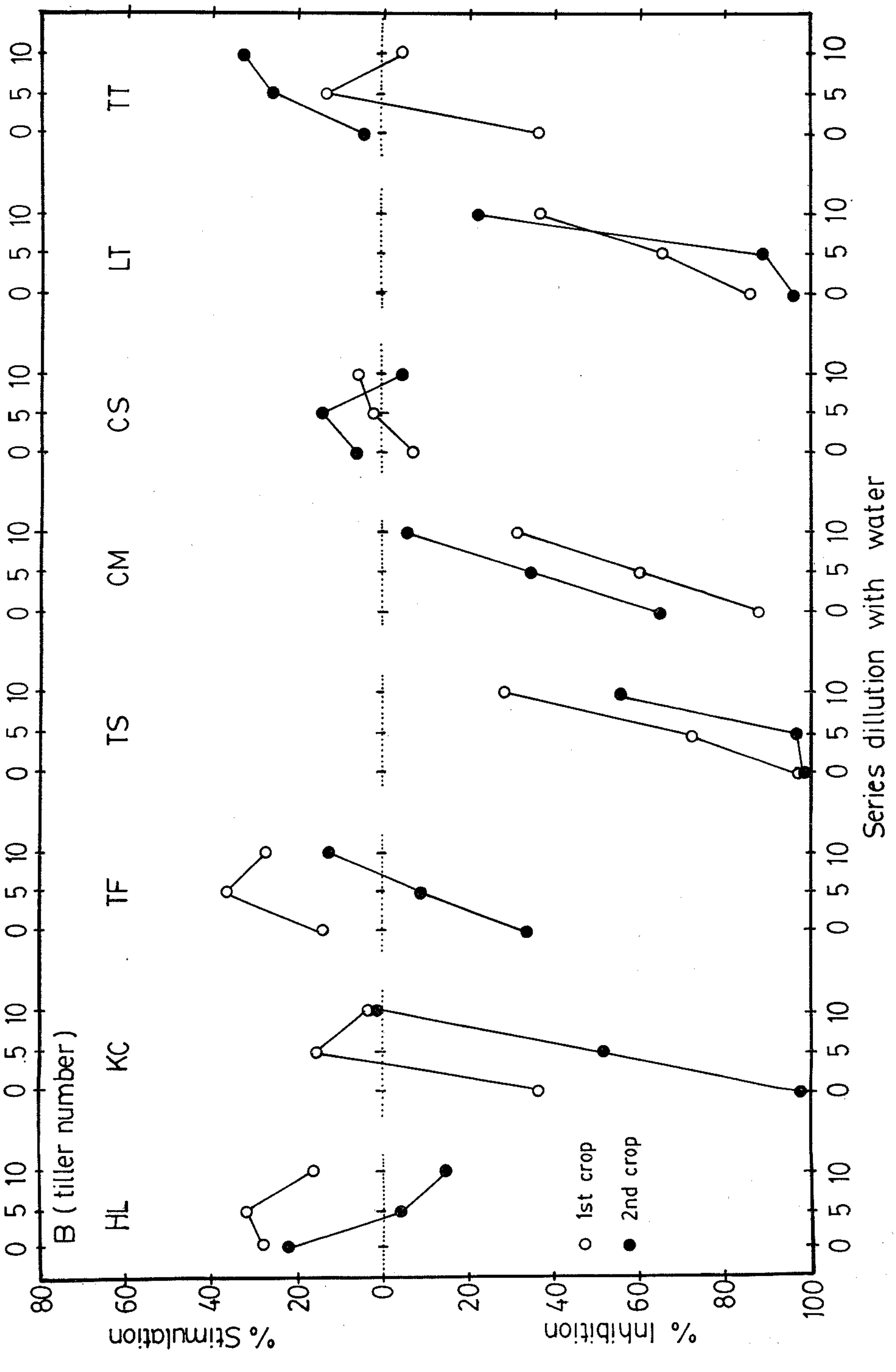
B (tiller number)
HL
KC
TF
TS
CM
CS
LT
TT
1st crop
2nd crop
% Stimulation
% Inhibition
Series dillution with water

Fig. 3B

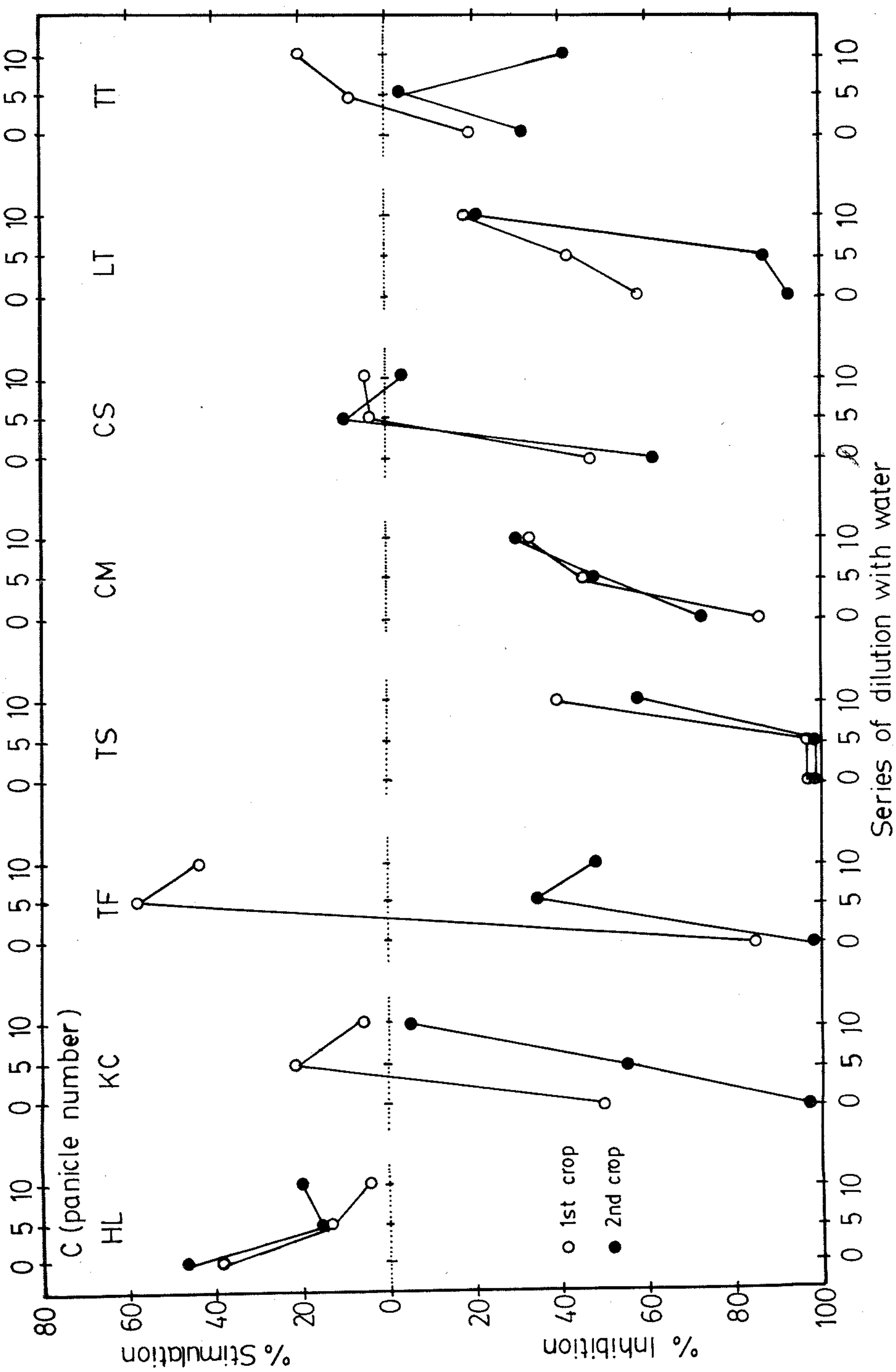
C (panicle number)
HL
KC
TF
TS
CM
CS
LT
TT
0 5 10
○ 1st crop
● 2nd crop
% Stimulation
% Inhibition
80
60
40
20
0
20
40
60
80
100
Series of dilution with water

Fig. 3C

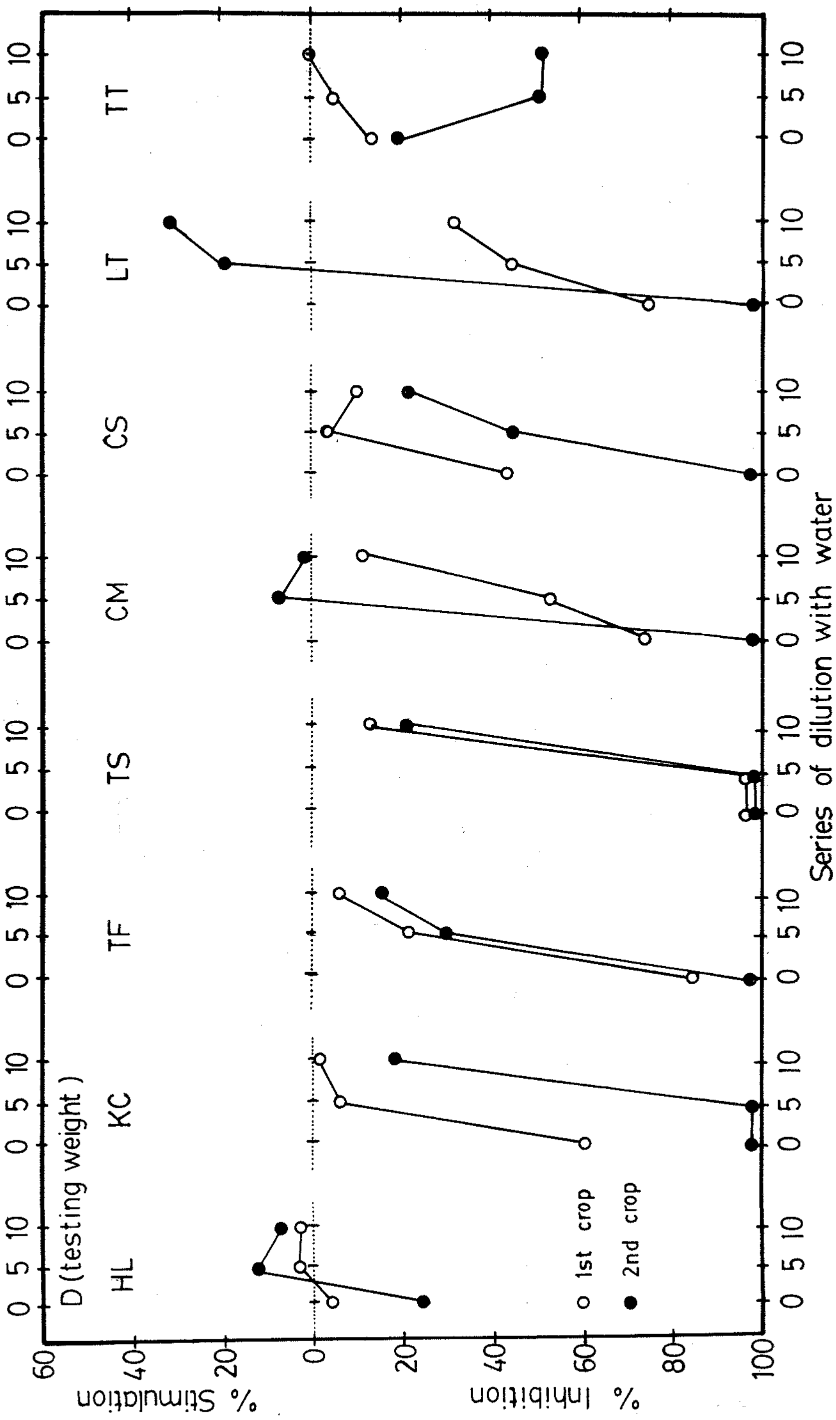
D (testing weight)
HL
KC
TF
TS
CM
CS
LT
TT
0 5 10
% Stimulation
% Inhibition
60
40
20
0
20
40
60
80
100
○ 1st crop
● 2nd crop
Series of dilution with water

Fig. 3D

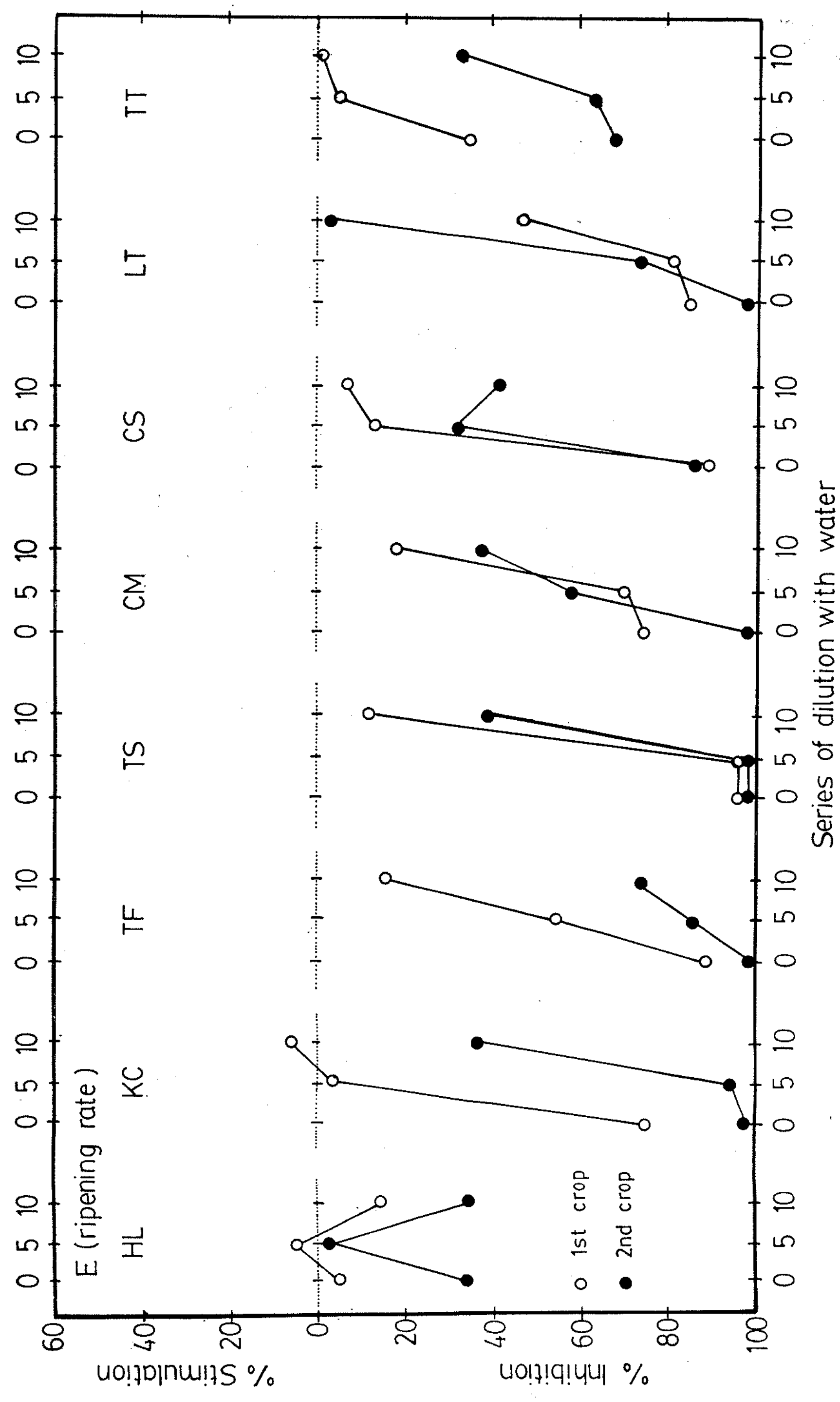
E (ripening rate)
HL
KC
TF
TS
CM
CS
LT
TT
0 5 10
○ 1st crop
● 2nd crop
% Stimulation
% Inhibition
60
40
20
0
20
40
60
80
100
Series of dilution with water

Fig. 3E

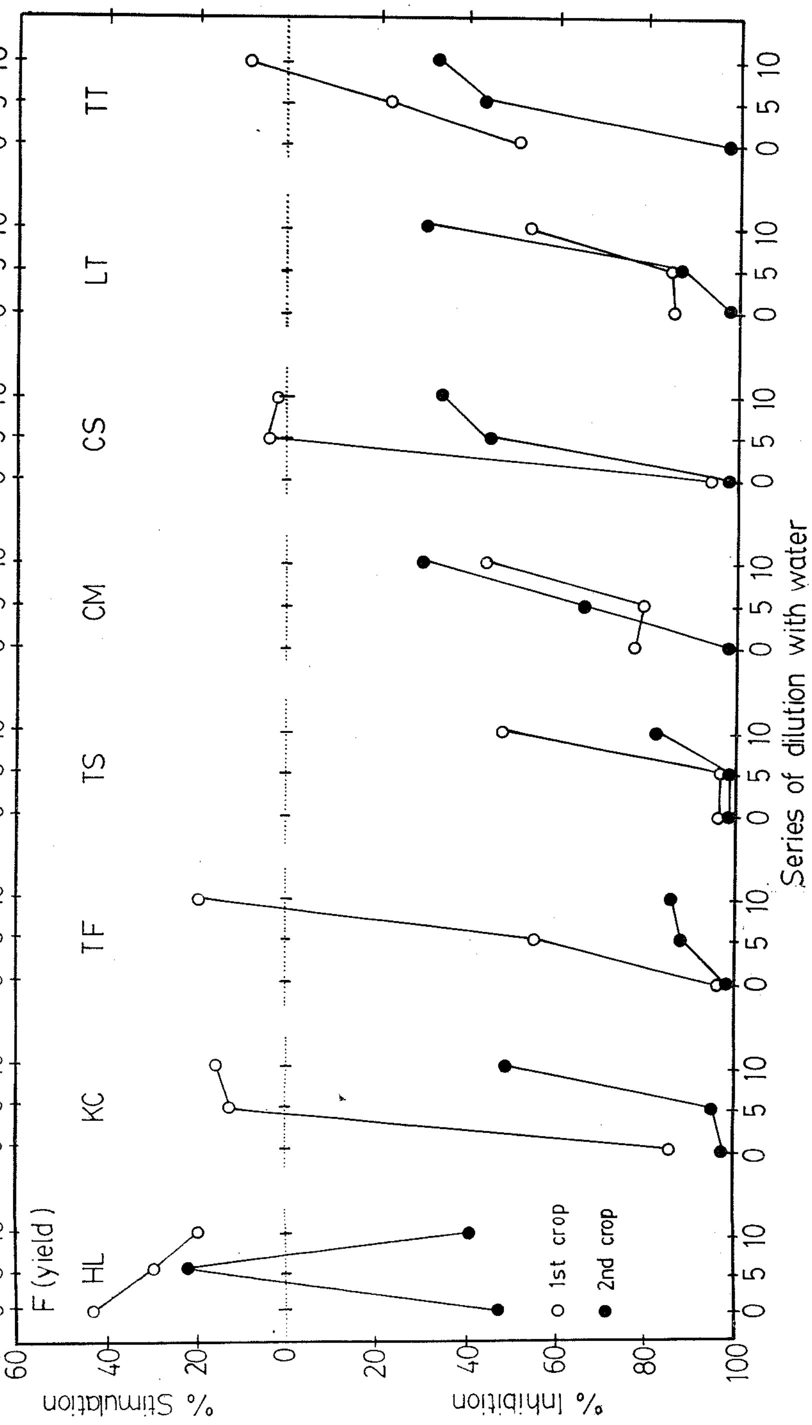
F (yield)
HL
KC
TF
TS
CM
CS
LT
TT
○ 1st crop
● 2nd crop
% Stimulation
% Inhibition
60
40
20
0
20
40
60
80
100
0 5 10
Series of dilution with water

Fig. 3F

Table 1. *Physicochemical properties of eight industrial waste waters sampling monthly in 1979.* The abbreviation of factories are: HL=Hwa-lung, KC=Kuan-chun, TF=Tai-fei, TS=Tai-sen, CM=Ching-mei, CS=Chia-shin, LT=Lian-ta, and TT=Ta-ting

Property	Standard	Factory	Sampling in 1979									
			February	March	April	May	June	July	August	September	October	November
EC (μmhos/cm at 25°C)	750	HL	526	1,391*	666	593	760*	485	—**	487	557	442
		KC	8,280*	6,100*	7,160*	5,743*	4,230*	5,670*	—	6,788*	—	4,690*
		TF	3,900*	3,245*	2,700*	3,096*	9,260*	3,510*	2,820*	4,042*	—	611
		TS	46,300*	15,625*	31,900*	19,803*	34,400*	28,400*	22,800*	16,983*	—	38,400*
		CM	321	—	1,150*	248	197	—	1,130*	—	—	5.130*
		CS	5,240*	5,010*	5,900*	2,470*	4,880*	4,980*	4,540*	—	4,825	426
		LT	8,110*	2,040*	874*	618	497	—	391	—	1,118*	7,560*
		TT	1,050*	777*	820*	618	659	535	668	—	1,805	620
Cl^- (mg/1)	175	HL	39	43	28	38	21	69	—	21	56	15
		KC	2,340*	1,761*	2,090*	2,415*	1,080*	1,010*	—	1,868*	—	1,340*
		TF	341*	110	130	112	2,240*	98	74	209	—	23
		TS	2,190*	2,071*	2,860*	2,993*	10,870*	6,450*	3,010*	2,538*	—	1,390*
		CM	24	—	74	41	38	—	34	—	—	93
		CS	300*	50	269*	181*	60	207*	241*	—	258*	209*
		LT	2,480*	105	154	121	58	—	54	—	176*	2,400*
		TT	82	37	106	53	85	138	143	—	81	77
pH	4-9	HL	8.9*	8.0	6.8	8.5	11.8*	6.6	—	6.4	7.4	9.2*
		KC	3.0*	4.2	5.2	3.2*	4.5	4.1	—	4.7	—	3.9*
		TF	9.4*	9.3*	10.4*	7.7	8.2	9.0	8.8	8.6	—	7.7
		TS	13.0*	12.4*	13.0*	10.3*	10.5*	11.7*	12.3*	12.0*	—	13.1*
		CM	7.1	—	9.8*	6.7	6.8	—	8.9	—	—	12.2*
		CS	7.4	7.6	7.0	7.3	7.0	7.0	6.9	—	7.2	7.5
		LT	8.1	7.3	7.5	6.9	7.3	—	7.4	—	6.9	7.4
		TT	6.2	8.2	7.4	5.4	9.0	6.1	3.5	—	2.4	8.3

Suspended solid (mg/1)	100	HL	41	—**	—	528*	272*	—	—	30	355*	115*
		KC	148*	293*	—	407*	472*	668*	—	485*	—	182*
		TF	—	—	—	—	—	—	—	16	—	—
		TS	438*	100	132*	124*	190*	296*	231*	160*	—	186*
		CM	44	—	64	25	—	—	—	—	—	72
		CS	380*	—	730*	367*	1,450*	850*	1,489*	—	1,020*	2,085*
		LT	548*	—	176*	12	82	—	—	—	61	—
		TT	—	—	—	—	—	—	—	—	—	—
SO_4^{-2}(mg/1)	200	HL	60	117	107	58	60	90	—	72	56	62
		KC	950*	314*	200	232*	240*	400*	—	193	—	300*
		TF	325*	503*	110	378*	800	203*	160	635*	—	140
		TS	13,500*	2,049*	1,320*	3.707*	32,500*	17,500*	1,120*	1,927*	—	950*
		CM	52		20	16	17	—	98	—	—	110
		CS	—	50	—	—	—	—	—	—	—	—
		LT	713*	105	72	66	41	—	78	—	105	145
		TT	50	37	118	140	62	42	44	—	81	58
NH_4^+—N(mg/1)	1	HL	—	—	—	—	—	—	—	—	—	—
		KC	—	—	250*	186*	160*	150*	—	—	—	—
		TF	745*	455.2	336*	349*	720*	420*	405*	—	—	—
		TS	—	—	—	—	—	—	—	—	—	—
		CM	—	—	—	—	—	—	—	—	—	—
		CS	455*	463*	526*	220*	446*	460*	350*	—	—	—
		LT	53*	6.2*	2.6*	0.51	2.8*	—	0.36	—	—	—
		TT	—	—	—	—	—	—	—	—	—	—

*: Data were beyond the standards for irrigation water for agricultural land in Taiwan (1978).

**: Data not detected

Table 2. *Cation contents of eight industrial waters in the monthly sampling of 1979*

Cation	Factory	Sampling in 1979									
		February	March	April	May	June	July	August	September	October	November
K^+ (mg/1)	HL	3.0	2.7	0.4	0.5	0.6	—	—	—	—	—
	KC	20.0	30.6	3.5	2.2	1.9	—	—	—	—	—
	TF	3.3	7.9	0.7	0.5	1.5	—	—	—	—	—
	TS	261.0	158.0	678.0	218.8	156.0	—	—	—	—	—
	CM	6.3	—	16.3	0.5	0.3	—	—	—	—	—
	CS	71.0	54.0	36.0	21.0	35.0	—	—	—	—	—
	LT	14.3	4.7	0.3	0.2	0.2	—	—	—	—	—
	TT	29.7	12.0	3.7	3.0	0.8	—	—	—	—	—
Na^+ (mg/1)	HL	85.0	117.1	67.0	66.0	100.0	17.0	33.2	32.0	53.0	45.0
	KC	463.0	330.1	381.0	229.5	239.0	204.0	—	336.5	363.8	210.0
	TF	0.5	48.0	319.0	57.8	417.0	22.0	33.0	58.8	90.8	17.0
	TS	370.5	516.2	1916.0	1502.5	5250.0	877.0	715.0	711.3	676.7	770.0
	CM	70.3	—	14.0	27.0	—	14.0	180.0	—	—	468.0
	CS	107.7	100.3	78.0	47.0	93.0	64.0	114.0	—	98.3	56.0
	LT	628.7	222.7	70.0	54.0	51.0	—	34.0	—	105.8	653.0
	TT	103.7	101.7	62.0	39.0	70.0	54.0	44.0	—	37.0	73.0
Ca^{+2} (mg/1)	HL	7.0	10.9	10.7	7.7	1.2	14.8	—	12.8	10.8	10.1
	KC	63.5	34.5	30.4	24.9	31.5	28.0	—	38.4	41.8	28.1
	TF	0.3	2.1	0.4	1.2	6.6	0.2	1.3	7.9	12.5	17.1
	TS	0.4	6.7	11.2	3.0	7.4	2.1	1.4	2.7	1.2	2.4
	CM	6.4	—	2.3	1.5	—	1.7	0.5	—	—	0.2
	CS	3.1	3.1	3.6	3.1	1.7	5.4	7.5	—	5.2	5.9
	LT	42.5	27.9	9.4	19.4	5.4	—	7.3	—	15.2	22.8
	TT	6.4	3.6	4.0	7.2	2.9	8.3	8.6	—	8.2	2.4
Cr^{+6} (mg/1)	TT	92.0	4.1	0.0	95.0	0.0	0.0	1.1	—	2.0	—
Mg^{+2} (mg/1)	HL	16.0	7.4	16.0	10.8	1.0	13.7	—	8.9	8.4	9.0
	KC	26.0	96.0	14.0	42.3	118.0	63.8	—	65.8	50.2	30.0
	TF	13.0	14.3	6.0	17.2	90.0	10.6	2.0	8.8	6.7	2.0
	TS	3.0	7.2	2.0	4.7	6.0	0.2	0.1	0.2	0.1	0.0
	CM	5.9	—	5.0	7.0	—	4.0	1.9	—	—	0.1
	CS	0.9	1.3	9.0	10.0	20.0	4.8	4.1	—	5.6	12.3
	LT	26.0	12.0	13.0	9.0	3.5	—	3.5	—	4.5	7.6
	TT	15.0	8.0	12.0	8.0	10.0	11.5	10.4	—	10.1	9.1

Fe^{+2} (mg/1)	HL	0.1	0.1	0.2	0.1	0.2	0.1	—	0.1	0.1	0.3
	KC	0.6	1.7	3.4	2.8	3.0	2.0	—	1.6	2.5	2.4
	TF	0.3	0.3	0.3	0.5	0.6	0.0	0.1	0.1	0.1	0.7
	TS	1.6	4.3	1.8	2.4	2.0	0.1	0.1	0.2	0.3	1.5
	CM	0.1	—	0.0	0.0	—	0.1	0.1	—	—	0.1
	CS	0.3	0.7	0.3	0.4	0.2	0.3	0.2	—	0.3	1.1
	LT	0.1	0.3	0.0	0.0	0.3	—	0.0	—	0.1	0.1
	TT	1.5	0.4	0.0	0.4	0.3	0.0	1.3	—	15.8	0.1
Mn^{+2} (mg/1)	HL	0.4	0.3	0.5	0.4	0.5	0.1	—	0.1	0.2	0.4
	KC	0.1	0.2	0.1	0.4	0.4	0.7	—	0.8	0.9	0.4
	TF	0.5	0.4	0.5	0.6	0.5	—	—	0.3	0.4	0.6
	TS	0.2	0.4	0.3	0.1	0.1	0.4	0.4	0.4	0.5	0.6
	CM	0.1	—	0.1	0.0	—	0.1	0.1	—	—	0.0
	CS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	—	0.2	0.2
	LT	0.1	0.1	0.1	0.1	0.0	—	0.1	—	0.1	0.5
	TT	0.2	0.2	0.2	0.8	0.1	0.7	0.7	—	0.8	0.3
Cu^{+2} (mg/1)	HL	0.2	0.3	0.1	0.0	0.0	0.1	—	0.0	0.2	0.1
	KC	0.1	0.1	0.1	0.1	0.1	0.1	—	0.1	0.1	0.1
	TF	0.3	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1
	TS	0.1	0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1
	CM	0.0	—	0.1	0.0	0.0	—	0.0	—	—	0.2
	CS	0.1	0.0	0.1	0.1	0.2	0.1	0.1	—	0.1	0.1
	LT	0.1	0.0	0.0	0.0	0.0	—	0.0	—	0.1	0.1
	TT	6.4	1.1	5.4	2.4	0.4	4.1	3.1	—	2.4	1.5
Zn^{+2} (mg/1)	HL	0.12	0.05	0.03	0.08	0.05	0.03	—	0.05	0.06	0.00
	KC	0.27	0.17	0.14	0.16	0.19	0.07	—	0.05	0.14	0.23
	TF	0.16	0.02	0.07	0.04	0.05	0.07	0.04	0.03	0.04	0.05
	TS	0.18	0.67	0.08	0.10	0.12	0.06	0.08	0.07	0.17	0.15
	CM	0.05	—	0.34	0.06	0.07	—	0.06	—	—	0.04
	CS	0.12	0.21	0.07	0.10	0.15	0.02	0.12	—	0.06	0.08
	LT	0.07	0.04	0.07	0.07	0.04	—	0.04	0.1	0.11	0.04
	TT	9.70	0.07	1.07	4.28	1.39	1.36	1.64	—	2.17	0.31
SAR**	HL	4.02*	6.70*	3.00	3.59	16.73*	0.76	—	1.67	2.91	2.48
	KC	12.27*	6.49*	14.28*	6.44*	4.35*	4.85*	—	7.62*	8.94*	6.52*
	TF	0.03	2.58	27.20*	2.91	9.16*	1.43	4.09*	3.41	5.13*	1.03
	TS	43.54*	32.52*	138.83*	12.63*	345.85*	158.83*	155.45*	114.56*	154.84*	139.50*
	CM	4.78*	—	1.17	2.05	—	1.33	25.26*	—	—	203.50*
	CS	13.37*	11.78	4.99*	2.91	4.30*	4.77*	8.27*	—	7.12*	2.96
	LT	18.59*	8.80*	3.45	2.53	4.19*	—	2.60	—	6.13*	30.21*
	TT	5.07*	6.80*	3.51	2.36	4.34*	2.83	2.36	—	2.04	4.80*

* Data were beyond the standards for irrigation water for agricultural land in Taiwan (1978).

** $SAR = Na \times [\frac{1}{2}(Ca^{+2} + Mg^{+2})]^{-1/2}$

which was toxic to plant growth, the causes of phytotoxicity were investigated. During 10 monthly samplings of each waste water, the physicochemical properties, namely electrical conductivity (EC), pH, and contents of suspended solids, Cl^-, SO_4^{-2} and NH_4^+-N were determined. Results of the analyses are given in Table 1, where the first column shows the standards for irrigation water for agricultural land (the data were made by a conference on standard of irrigated water for agricultural land. Taipei, 1978). As far as electrical conductivity (EC) was concerned almost all waste waters exhibited EC values much higher than the standard set at 750 μmhos/cm at 25°C. Among eight factories, the waste waters from the Kuan-chun (KC), Tai-fei (TF), Tai-sen (TS), Chia-shin (CS), and Lian-ta (LT) factories revealed extremely high EC values, and the TS was the highest. It seemed to be that the quality of waste water was very bad throughout the year round (Table 1). Regarding pH value of the waste waters, the KC water was very acidic whereas the TF and TS waters were alkaline. The pH of these waters was also outside the range of the standards for agricultural irrigation (pH 4–9).

The Cl^- contents in the KC and TS waters were also higher than the standard (set at 175 mg/1) for irrigation water. As far as suspended solid was concerned, the HL, KC, TS, and CS waters revealed significantly higher values than the standard (100 mg/1) for irrigation water, and the CS water exhibited the highest value among them. Regarding the contents of sulfate ion (SO_4^{-2}) in the waste waters, the KC, TF and TS showed the values exceedingly far outside the range of the standards set at 200 mg/1, and the TS water exhibited the highest value. The results of analyses of NH_4^+-N contents in the waste waters revealed that the Tai-fei (TF) and Chia-Shin (CS) waters contained high amount; undoubtly, the main components of these waters was ammonium product. The NH_4^+-N content in the CS water analyzed in recent years has been exceedingly high. It is likely that no improvement of the waste water has been made.

The results of analyses of the cation contents of the waters are given in Table 2. Since the main pollutant produced from the waste water, except from the Ta-tung factory, was not heavy metal, the contents of Cu, Zu and Cr were very low. However, the Na contents in some industrial waste waters were very high, causing high SAR value, where the SAR (sodium aborption ratio) was obtained from a formula: $Na^+ \times [\frac{1}{2}(Ca^{+2}+Mg^{+2})]^{-1/2}$, and the safety value of SAR for irrigation was 4. Above this value, the soil would be polluted and caused sodium toxicity. It was found that many of the aforementioned water gave the SAR values above 4, which indicated that the waste

Table 3. *Physicochemical properties of 4 industrial waste waters sampling on March 14–15, 1979*

Property	Factory	Sampling time within 24 hr						
		04:00	08:00	12:00	16:00	20:00	24:00	Average
EC (μmhos/cm at 25°C)	HL	467	5820*	550	644	448	417	1391*
	KC	5720*	7470*	6390*	6070*	7550*	3400*	6100*
	TF	3150*	3480*	3380*	3510*	3090*	2860*	3245*
	TS	18400*	9750*	11200*	29900*	12600*	11900*	15625*
pH	HL	7.2	12.2*	7.1	7.4	7.1	7.2	8.0
	KC	3.3*	2.5*	4.0	3.7*	4.3	6.3	4.2
	TF	9.2*	9.5*	9.5*	9.2*	9.5*	9.3*	9.3*
	TS	12.2*	12.3*	12.2*	12.7*	(1.4)*	(1.4)*	12.4*
Cl^- (mg/l)	HL	33	54	40	45	—**	—	43
	KC	1720*	2100*	1860*	1740*	2260*	885*	1760*
	TF	111	109	179*	99	89	75	110*
	TS	4250*	823*	1110*	5480*	774	764*	2071*
SO_4^{-2} (mg/l)	HL	56	250*	93	72	—	—	117
	KC	395*	190	380*	320*	440*	160	314*
	TF	430*	580*	600*	630*	455*	325*	503*
	TS	850*	525*	1620*	4700*	2300*	2300*	2049*
Suspend solid (mg/l)	HL	—	—	—	—	—	—	—
	KC	325*	—	280*	—	275*	—	293*
	TF	—	—	—	—	—	—	—
	TS	132*	—	132*	—	37	—	100
NH_4^+-N (mg/l)	TF	350*	585*	543*	455*	378*	420*	435*

* Beyond the standards for irrigation water for agricultural land.
** (—) Not detected

water contained too much high amount of sodium and would be harmful to the paddy soil and resulted in the reduction of agricultural productivity.

Furthermore, the results of physicochemical analyses on water samples collected six times a day are given in Table 3. In general, there has no definite distribution pattern of measurement in a day, and the value of each measerement varied with time. Regarding the EC values, the KC, TF and TS water showed extremely high values that agreed with those of monthly sampling. The data of rest physicochemical properties were also shown very much variable with sampling time. The cation compositions of the waste waters are shown in Table 4. It was found that sodium content was very high thus the SAR values in Table 4 were far beyond the standard criteria for irrigation water. This concluded that the reduction of rice yield in this study might be in part attributed to the sodium toxicity in soil.

Table 4. *Cation contents of 4 industrial waste watrrs sampling on March 14–15, 1979*

Cation (ppm)	Factory	Sampling time within 24 hr						
		04:00	08:00	12:00	16:00	20:00	24:00	Average
Na^+	HL	52.2	441.7	69.3	86.0	53.0	46.0	117.1
	KC	340.3	254.0	367.3	367.7	386.3	267.7	330.6
	TF	60.0	40.3	63.3	41.3	43.3	40.3	48.1
	TS	693.7	478.7	650.0	695.3	321.3	258.3	516.2
K^+	HL	2.0	4.0	3.0	2.0	4.0	1.0	2.7
	KC	32.2	26.0	33.7	43.0	30.0	18.7	30.57
	TF	7.0	4.0	26.3	3.7	2.0	3.7	7.86
	TS	211.0	143.0	125.7	398.5	36.3	39.0	158.9
Ca^{+2}	HL	11.25	0.00	16.90	16.40	8.79	12.34	10.95
	KC	30.80	35.20	37.60	33.70	27.00	42.90	34.50
	TF	1.98	2.07	1.65	2.63	2.68	1.76	2.14
	TS	11.46	1.81	2.30	4.29	13.56	6.66	6.98
Mg^{+2}	HL	13.0	0.1	7.0	3.0	6.0	5.0	7.35
	KC	108.0	72.0	90.0	80.0	94.0	132.0	96.00
	TF	15.0	16.0	10.0	16.0	14.0	15.0	14.30
	TS	7.0	4.0	14.0	2.0	6.0	10.0	7.17
Fe^{+2}	HL	0.10	0.00	0.18	0.06	0.03	0.02	0.07
	KC	1.93	0.39	3.03	0.44	2.69	1.61	1.68
	TF	0.19	0.26	0.27	0.36	0.26	0.40	0.29
	TS	1.51	1.29	1.55	1.60	9.88	10.24	4.35
Mn^{+2}	HL	0.38	0.33	0.49	0.37	0.34	0.40	0.32
	KC	0.10	0.01	0.36	0.03	0.27	0.23	0.17
	TF	0.44	0.50	0.45	0.63	0.52	0.53	0.43
	TS	0.10	0.17	0.09	0.15	1.01	0.34	0.35
Cu^{+2}	HL	0.21	0.33	0.24	0.36	0.27	0.28	0.28
	KC	0.04	0.05	0.03	0.06	0.07	0.06	0.05
	TF	0.04	0.04	0.03	0.04	0.03	0.03	0.04
	TS	1.51	1.29	1.55	1.60	9.88	10.24	4.35
Zn^{+2}	HL	0.14	0.00	0.07	0.04	0.05	0.01	0.05
	KC	0.19	0.21	0.25	0.16	0.17	0.04	0.17
	TF	0.05	0.00	0.01	0.02	0.00	0.04	0.02
	TS	0.45	0.03	0.01	0.18	3.35	2.82	0.67
SAR**	HL	2.46	274.29*	3.54	5.12*	3.33	2.78	45.59*
	KC	6.43*	5.60*	7.36*	7.84*	7.85*	4.55*	6.61*
	TF	3.18	2.06	4.10	2.12	2.32	2.13	2.65
	TS	39.68*	45.24*	35.33*	68.70	18.14*	15.60*	37.12*

* Data were beyond the standarads for irrigation water for agricultural land.
** See Table 2.

Discussion

In last few years we have studied more than 30 industrial waste waters, and concluded that almost all waste waters exhibited remarkable phytotoxic effects on the radicle growth and seed germination of rice and lettuce and suppressed the growth and yield of rice plants grown in pots (Chou, 1978; Chou *et al.*, 1979; 1980). In addition to the last year study which included the Chia-shin (livestock), Ching-mei (dye), Lian-ta (leather), and Ta-tung (plating), we selected another four factories, namely Hwa-lung (synthetic fiber), Kuan-Chun (food), Tai-fei (fertilizer), and Tai-sen (dye) to study the effects of these industrial waste waters on crop growh. In general, the results of repeat study of the first four waste waters agreed with those of last year, while the additional four also showed phytotoxic effects. The order of toxicity was Chia-shin≧Tai-fei>Tai-sen>Kuan-chun>Hwa-lung>Ta-tung>Lian-ta>Ching-mei. However, the order of toxic effect on rice yield was slightly different from that order. The major cause of the phytoxicity was high electrical conductivity which reflected the amount of Cl^-, SO_4^{-2}, NH_4^+-N and content of metal. For example, the Chia-shin, Kuan-chun, Tai-fei, and Tai-sen waters were apparently due primarily to the high value of electrical conductivity, and the values of these waters were far beyond the standard set for irrigation water. The toxic effects of the Kuan-chun, Tai-fei, Tai-sen and Chia-shin were also due to high content of Cl^-, suspended solid, SO^{-2} and NH_4^+-N. Because of high values of these physicochemical properties, the waters revealed pH values either very high or low and the values were also beyond the standard for irrigation water. The toxicity of the Ta-tung water was likely due to the high content of Cr^{+6}. It is likely that the toxicity of each water was not only caused by one single factor, but also by several factors together. Furthermore, the analyses of cations showed that the sodium content was extremely high in the toxic waters, indicating that sodium toxicity would be existed in the soil receiving such water. If this is the case, the soil receiving the high content of sodium as expressed by SAR will be jeopardized, resulting in poor fertility, high salinity and soil texture change. Moreover, the long term accumulation of Zn, Cu, and Cr causes soil toxicity, resulting in a detrimental effect on plant growth. The unique chemical waste released from a factory may change soil microflora and fauna, and in turn result in an imbalance of the agricultural ecosystem. This will be particularly pronounced in the paddy fields of Taiwan not only the land receiving the waste waters but also from the use of herbicides and pesticides by farmers. After the land were polluted by waste waters, the fertility of soil would never return to its previous status, and naturally the agricultural productivity will be decreased (Chou, 1978;

WQS, 1969). The evaluation of present study is therefore very helpful in understanding the detrimental impacts of industrial waste pollutants on the agricultural ecosystem and as this help in preserving our lands in a high state of productivity, thus insuring a prospective future for the coming generations.

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臺灣區內水污染對農作物生長之影響 V.

染整、家畜、電鍍、製革、合成纖維、食品、及肥料廠之廢水之毒性影響

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從本省桃園新竹地區的工廠中選出八家代表工廠即：景美及臺森染整廠、嘉新畜產場、大同電鍍廠、聯大製革廠、華隆合成纖維廠、冠軍食品廠及臺灣肥料廠。從一九七九年二月至十一月間，每月各一次的採樣及在三月、五月及九月中各選一天，並在該天24小時中做每隔4小時的連續採樣。所採之廢水帶回實驗室後立即過濾，爾後貯藏於 4°C 至 5°C 之冷藏室中。一部份的廢水用來做對水稻及萵苣之生物分析及水稻之盆栽實驗，另一部份用來做有關因子之水質分析。生物分析及盆栽實驗用以檢驗各廢水對農作物之毒性程度，而水質分析用以檢定其毒性之原因。生物分析的結果顯示上述各廠之廢水對水稻及萵苣都具有極顯著的毒性。並以萵苣最為敏感。各廠廢水之植物毒性依秩為嘉新≧臺肥＞臺森＞冠軍＞華隆＞大同＞聯大≧景美。其毒性與採樣之月份及時間並無相關性。對水稻（臺南五號）的盆栽實驗言，大多數的廢水均顯著地抑制水稻的生長如分櫱數，根葉、及稻稈，並抑制其產量構成因子如穗數，千粒重，稔熟率及產量。廢水經稀釋五倍或十倍後，其毒性銳減。對水稻生長之抑制情形以第二期作最為明顯。盆栽的實驗結果與生物分析者大致吻合。上述各廢水之水質分析結果顯示，大多數之廢水均超過本省農業灌溉之水質標準；尤其以電導度， pH，懸浮固體量、氯離子、硫酸根離子、氮離子、及鈉離子及銅、鋅、鉻等重金屬為主要原因。雖各廠廢水之毒性原因不盡相同，但其毒性與其構成毒害之上述因子呈正相關關係。