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IMPACTS OF WATER POLLUTION ON CROP GRWOTH IN TAIWAN IV. THE HSINCHU AND TAOYUAN AREAS[1]

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Abstract

The detrimental effects of industrial waste waters on crop growth around Hsinchu and Taoyuan areas were studied. Waste waters coming from seven factories namely Chunghwa, Ching-mei, Chia-shin, Lian-ta, Kuo-tai, Ta-tung and Shuang-shii were analyzed for their phytotoxicity and physicochemical properties. The effect of the waters on the growth and yield of rice plants *(Oryza sativa* Tainan 5) was undertaken in pots. The bioassay results clearly showed that the waste waters exhibited significant phytotoxic effects on the radicle growth of rice, lettuce and rye grass. Lettuce was the most sensitive species to waste water, rice the second, and rye grass the least. The phytotoxicity varied with industrial waste water and with time of sampling. The order of phytotoxicity among seven waters is Chia-shin > Lian-ta > Ta-tung > Kuo-tai > Shuang-shii > Ching-mei > Chung-hwa. The toxicity was also found to be higher in the day time than in the evening. 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, test weight, and grain yield. The physicochemical analyses of these seven industrial waste waters revealed that the values were often above the limits of the standard criteria for irrigation water for agricultural land, and some of these properties were the cause of phytotoxic effects on plant growth. Electrical conductivity, pH, suspended solids, Cl^-, $SO_4^=$, NH_4^+–N, Na^+, and heavy metals of Cu, Zn, and Cr were the major detrimental factors, and the amount of each factor mentioned was significantly correlated with phytotoxicity.

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

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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. Not many publications dealing with this study have been reported (Chen, 1973; Chou, 1978; Chou *et al.,* 1978; Yang, 1976) yet substantial 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.,* 1975; Jeng, 1973; Levitt, 1972; Nieman, 1960; Tagawa *et al.,* 1963; WQS, 1969). Since 1977, under the auspices of JCRR, the present authors have studied the Hsinchu and Taoyuan areas, where a vast agricultural area was jeopardized by polluted water. We have focused our attention on this area and selected seven major factories in this area to asses the physicochemical nature of their waste waters and to elucidate the phytotoxic mechanisms of the polluted water. The results of 1977 have been reported (Chou *et al.,* 1979). As a result of the whole study, we were able to make conclusions and recommendations to relevant agencies to reduce or prevent further damage from polluted waters on crop growth.

Material and Methods

Sampling and preparation of waste water

Seven major kinds of industrial factories around the Hsinchu and Taoyuan areas were selected for this study, these were: paper (Shuang-shii), plastic (Kuo-tai), petroleum (Chung-hwa), livestock (Chia-shin), dye (Ching-mei), plating (Ta-tung) and leather (Lian-ta) 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 March 15, April 20, May 17, June 21, July 12, August 16, September 19, and October 16 of 1978. In addition, six samplings within a day were also made on May 30-31, July 21-22, August 16-17, and October 16-17. The samples were brought back to the laboratory of the Institute of Botany, Academia Sinica, and then were immediately filtered through Whatman 3 mm filter paper, and stored in a cold room (4°C) before assaying.

Pot experiment setting

This experiment was conducted in the Hsinchu District, Taiwan Provincial Agricultural Improvement Station. About 10 kg- soil collected from the Hsinchu experimental farm was placed in each pot (1/2000 acre size). Each treatment was set up by using a split design with 4 replicates. Each pot was filled with different waste water with a series of dilutions as 5X and 10X, where X means dilution foctor. 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 April 7 for the first crop and on August 10 for the second crop, while the harvest was made on July 19-20 and December 5 of 1978, respectively. During the growth period of the rice plants, the length of the rice seedlings and number of tillers were determined on the 30th, 60th, and 90th day after transplanting. At 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 phototoxicity 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:

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

then, the negative values expressed the stimulation effect.

The third bioassay technique described by Chou and Lin (1976) was used to determine the effect of industrial waste water on the root initiation of mungbeans. 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.

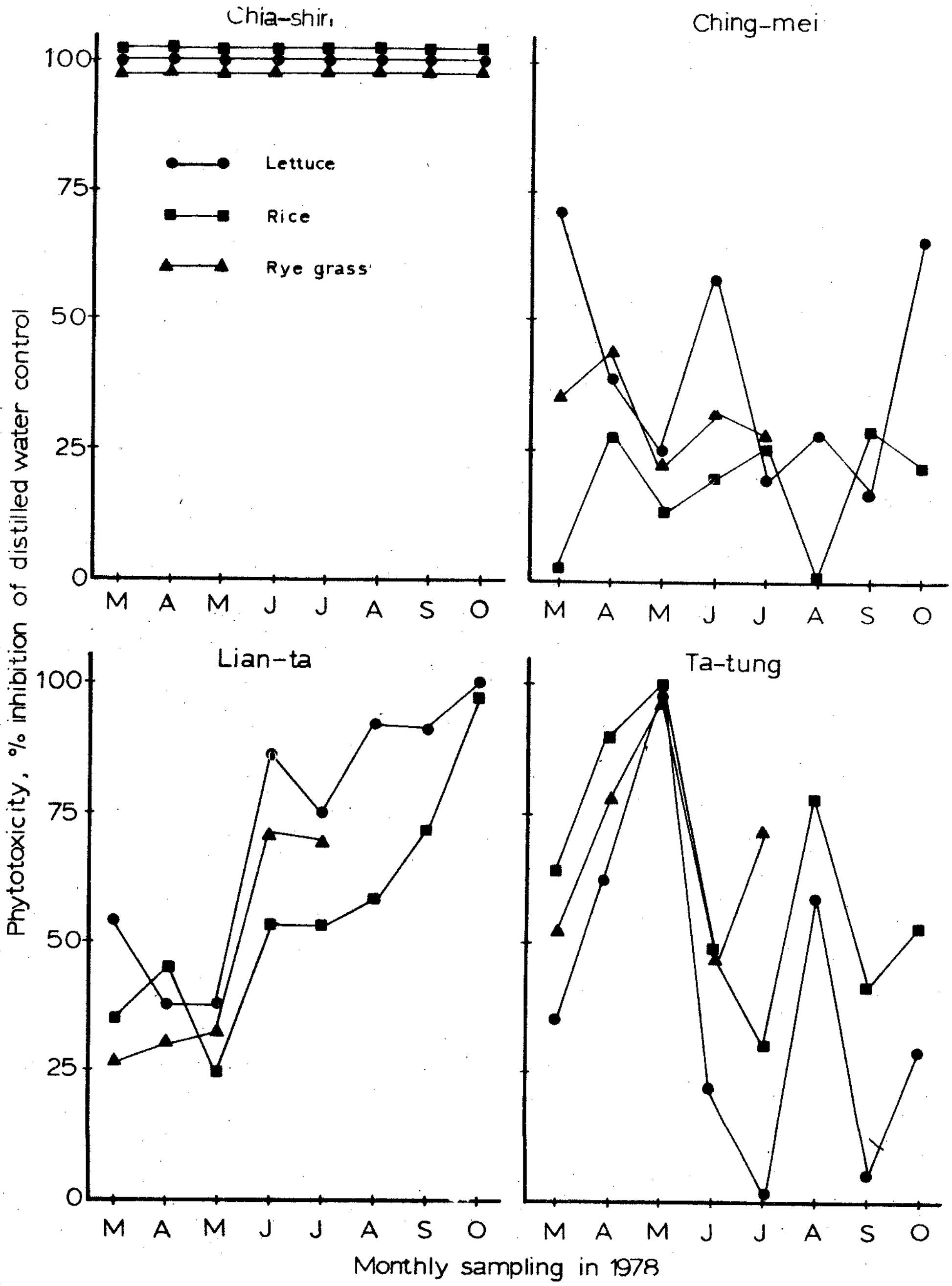
Physicochemical analysis of waters

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

Seven industrial waste waters collected monthly (from March to October 1978) were bioassayed on rice, lettuce and rye grass seeds. Results expressed as % 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 revealed a relatively high phytotoxicity on lettuce and low inhibition on rice. In addition, about two-thirds of the samples showed inhibition greater than 25%. In the first three monthly samplings of Lian-ta water the phytotoxicities range from 25% to 50%, but in the later samplings the toxicities were all above 50% and finally reached 100% in the October sample. In the Ta-tung waste water, the phytotoxicities revealed in March, April, May and August of 1978 were significantly higher than the rest. It was surprising that the inhibition of lettuce radicle growth was low. In the Shuang-shii and Chung-hwa waters, the phytotoxicities were generally low and only a few samples revealed a toxicity higher than 25%. However, in the Kuo-tai water, the toxicity was generally higher than 25% and only one-fifth of samples showed lower than 25% inhibition (Fig. 1).



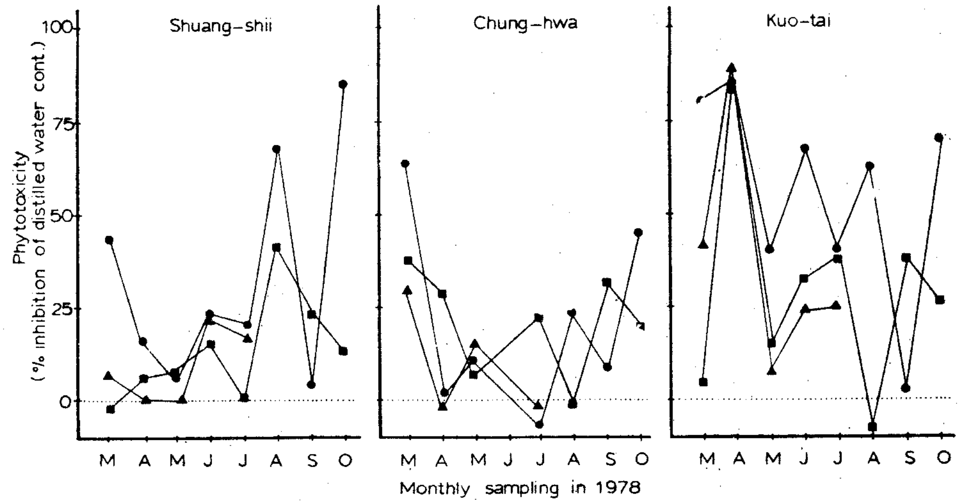


Fig. 1. The monthly phytotoxic effects of industrial waste waters from 7 factories, Chia-shin, Ching-mei, Lian-ta, Ta-tung, Shuang-shii, Chung-hwa and Kuo-tai on the radicle growth of lettuce, rice and rice plants. The phytotoxicities were expressed as % inhibition of radicle growth over distilled water control. The negative values indicate the % stimulation.

Furthermore, in order to understand how the phytotoxicity varied with time of day, six-samplings during a day were made and the results of the bioassay using rice and lettuce as test materials are shown in Figs. 2 and 3, respectively.

It was also found that the Chia-shin water revealed 100% inhibition on both rice and lettuce growth regradless of sampling time. The water of Lian-ta produced significantly phytotoxic effects on the radicle growth of rice and lettuce seeds, and the fact was particularly pronounced in the water collected from the day time (Figs. 2 and 3). The Ching-mei water reflected irregular phytotoxicity and was shown to be very toxic in the sample collected at 9:00 on May 30, 1979. In addition, lettuce was shown to be more senstivie to the water than rice was.

As far as the Ta-tung waters were concerned, the phytotoxicity appeared significantly higher in the day time period from 09:00 to 15:00 particularly at 9:00 o'clock sampling. No evening data were shown because the operation was not functioning in th evening.

It is conculded, based on eight months of sampling, that the phytotoxicity in general varied with the sampling times and is likely irregular: however, the order of phytotoxicity is Chia-shin > Lian-ta > Ta-tung > Kuo-Tai > Shuang-shii > Ching-mei > Chung-hwa. In addition, the toxicity was found to be generally higher in the day time, particularly at 9:00 o'clock, than in the evening. Furthermore, the Chia-shin water exhibited 100% inhibition in all sampling times regardless of monthly and daily sampling.

Detrimental effects of industrial waste waters on rice growth in pots.

Experiment I

The waste waters from Chung-hwa, Kuo-tai, and Shuang-shii were used to irrigate

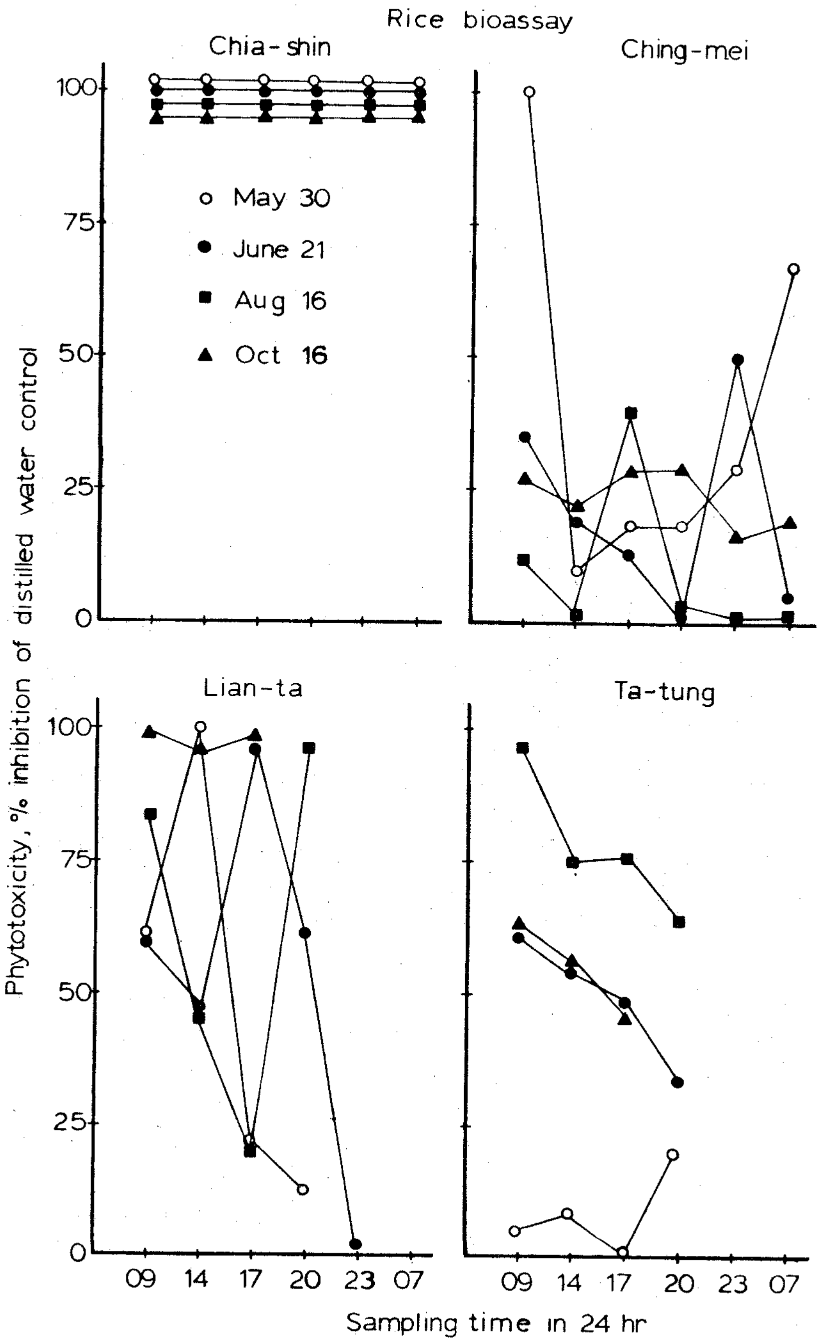


Fig. 2. The daily phytotoxic effects of 4 industrial waste waters on the radicle growth of rice. For the rest of the description, see Fig. 1.

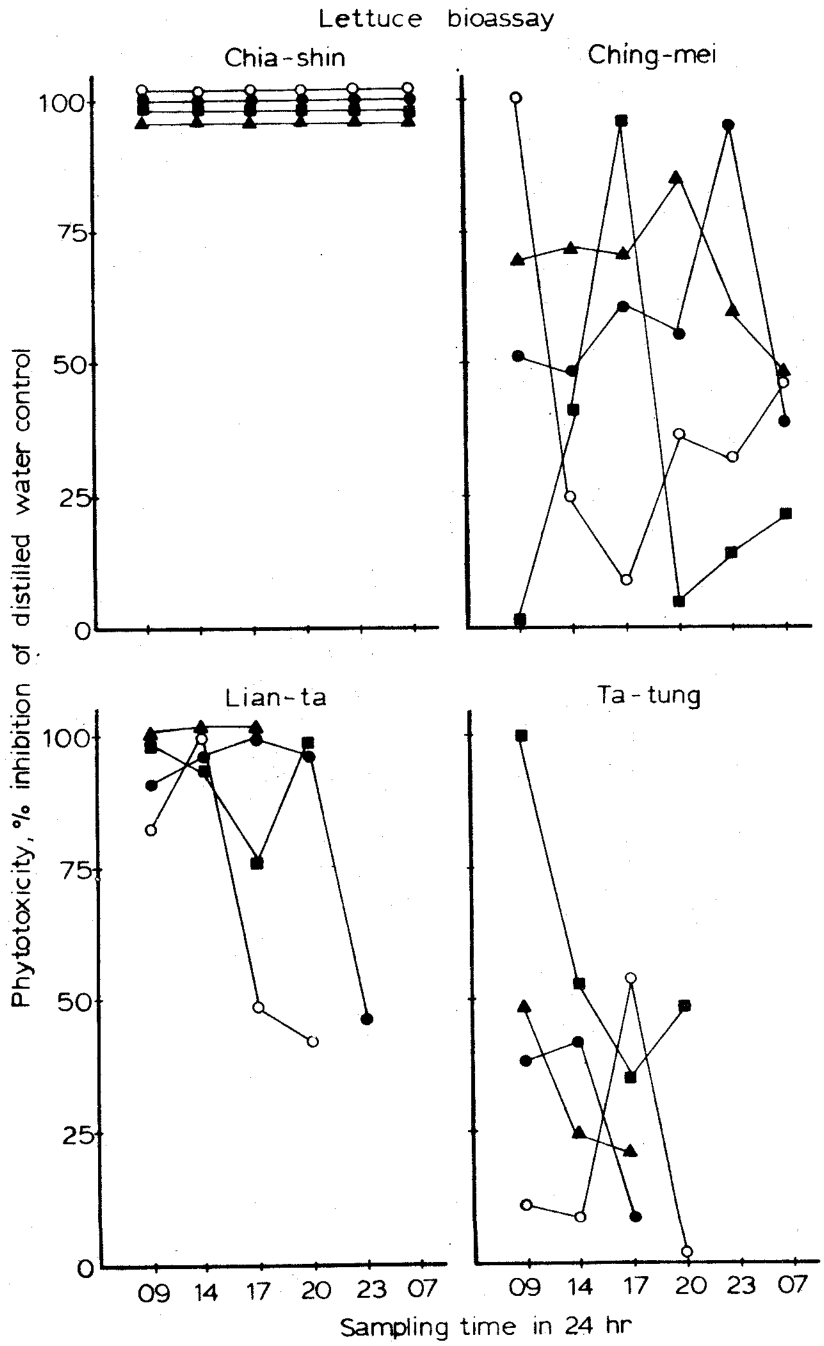


Fig. 3. The daily phytotoxic effects of 4 industrial waste waters on the radicle growth of lettuce.

rice plant (*Oryza sativa,* Tainan 5) grown in plastic pots. This was a repeat experiment of last year, and was set up in the Hsinchu Experimental Staiton. The growth and yield components of rice plants as affected by these three waters were examined. The rice plants were sampled at the 30th, 60th, and 90th day after transplanting and were harvested around the 115th day in the first crop season of 1978. The number of tillers, dry weight of straw and roots of rice plants were measured. Fig. 4 shows that there is insignificant difference among tap water and the other three industrial waste waters at the 30th of each sampling, but there is a significant difference among them at 60th and 90th of the sampling. Among these waters, Shuang-shii exhibited the highest inhibiton, Kuo-tai the next and Chung-hwa the least. As far as the yield component of rice plants as affected by the polluted waters was concerned, number of panicles and test weight were significiantly retarded by these three waste waters as compared with the tap water control (Fig. 5). However, ripening rate was not significantly different among tap water and 3 waste waters (Fig. 5). The results agree well with those of last year.

Experiment II

In addition to *Experiment I,* seven industrial waste waters, namely Chung-hwa (CH), Ching-mei (CM), Chia-shin (CS), Kuo-tai (KT), Lian-ta (LT), Shuang-shii (SS) and Ta-tung (TT) were used to irrigate rice plants (Tainan 5) as compared with the tap water as the control. The rice plants were grown in pots in 2 crop seasons and harvested during the mature stage. The agronomic characters and yield components of rice plants were examined among each test waste water, and the date were compared with results using tap water. The data expressed as % of tap water control are shown in Fig. 6 (A, length of straw; B, tillers; C, panicle numbers; D, test weight; E, ripening rate; F, yield).

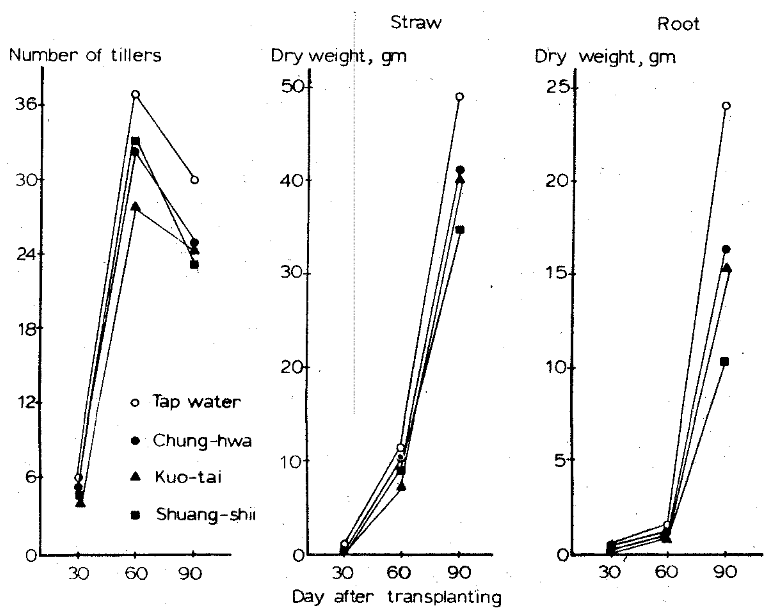


Fig. 4. The effects of 3 industrial waste waters and tap water on the growth of rice plants grown in pots.

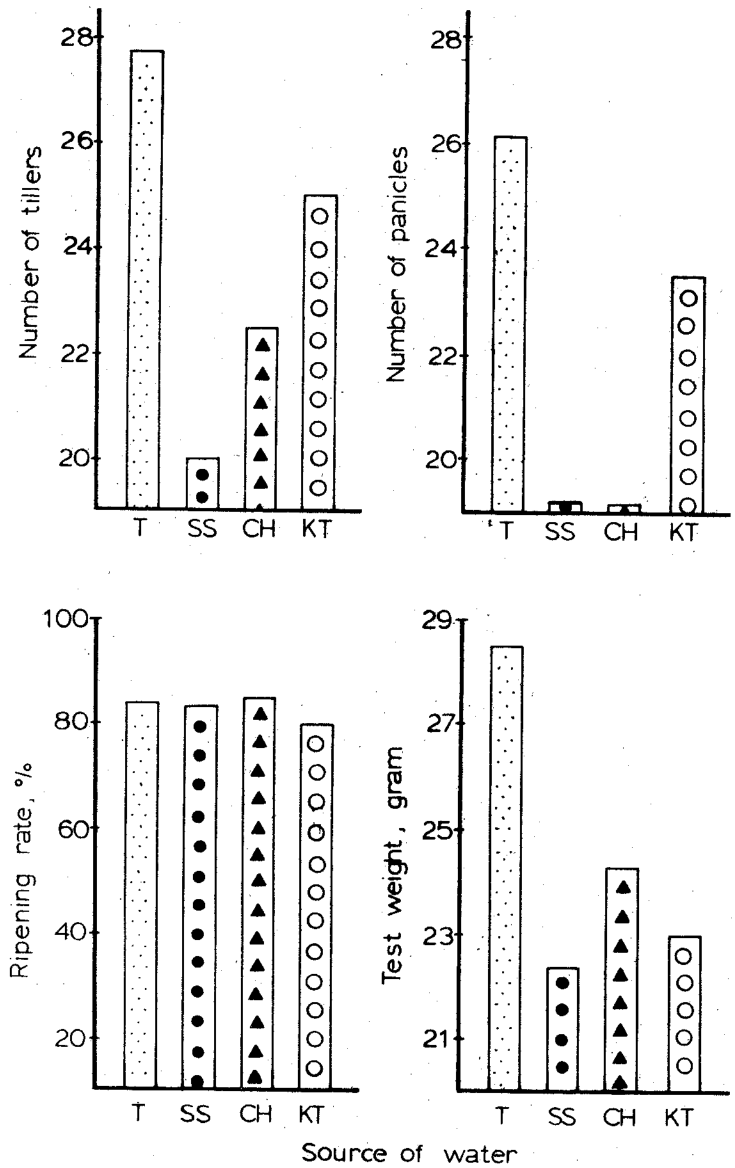


Fig. 5. The effects of 3 industrial waste waters and tap water on the yield components of rice plants grown in pots.

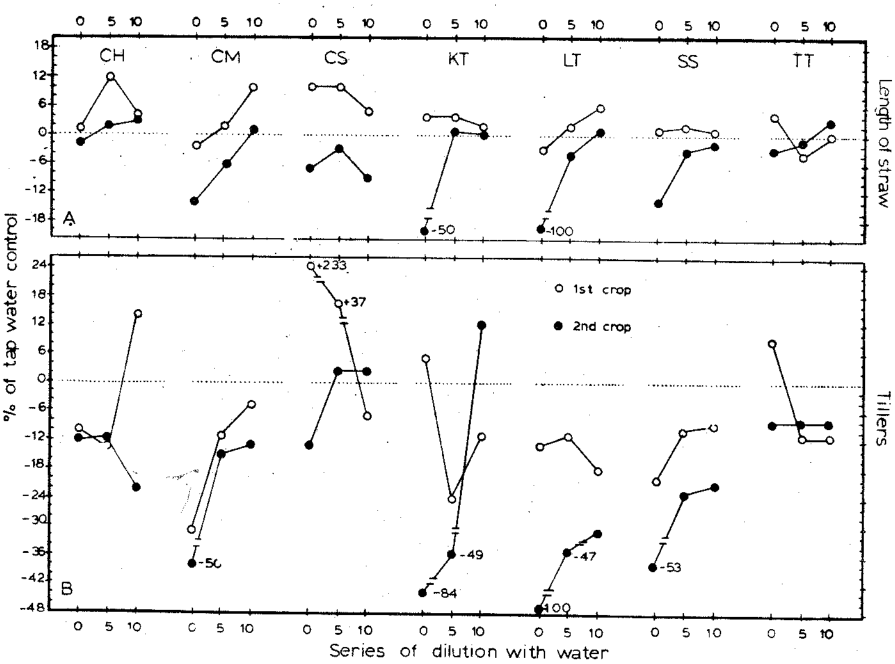
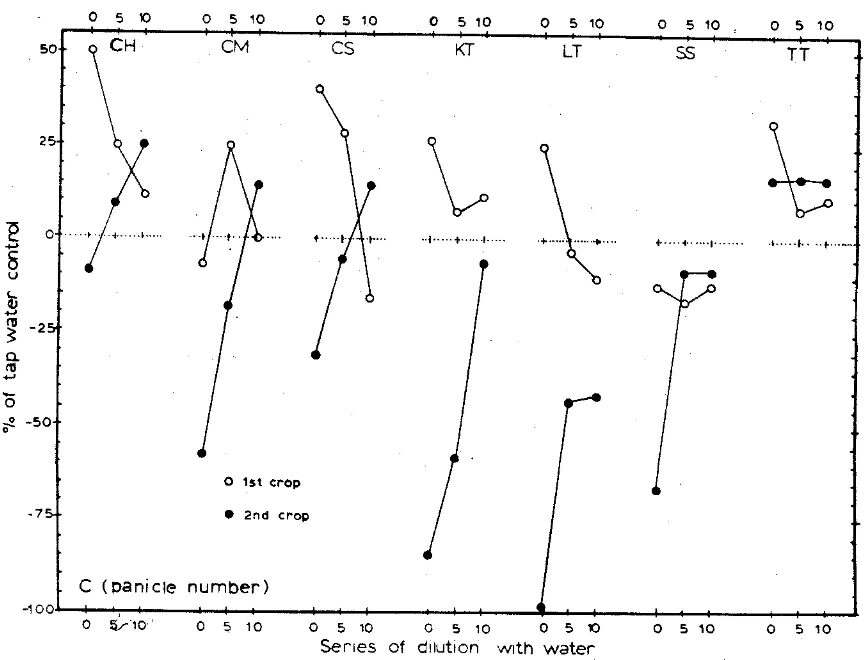

CH
CM
CS
KT
LT
SS
TT
A
B
Length of straw
Tillers
% of tap water control
o 1st crop
● 2nd crop
Series of dilution with water

Fig. 6A B


CH
CM
CS
KT
LT
SS
TT
% of tap water control
o 1st crop
● 2nd crop
C (panicle number)
Series of dilution with water

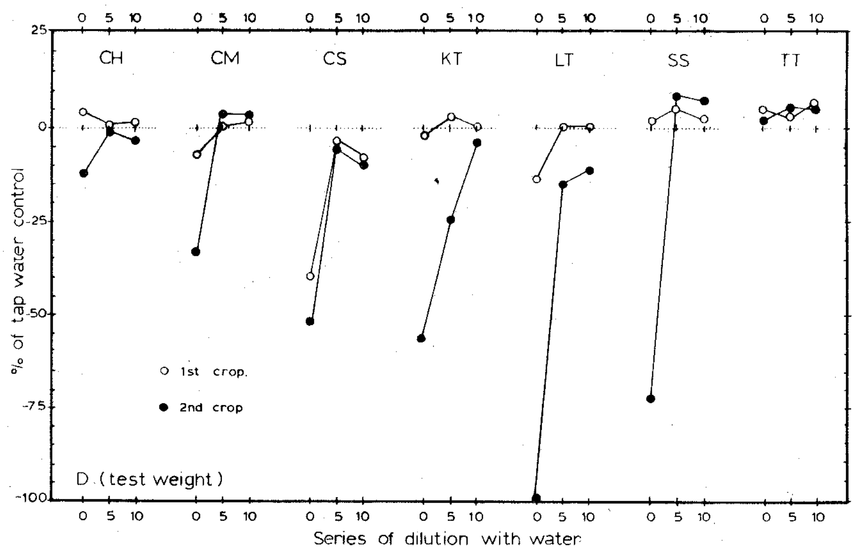

CH
CM
CS
KT
LT
SS
TT
0 5 10
25
0
-25
-50
-75
-100
% of tap water control
O 1st crop.
● 2nd crop
D (test weight)
Series of dilution with water

Fig. 6D

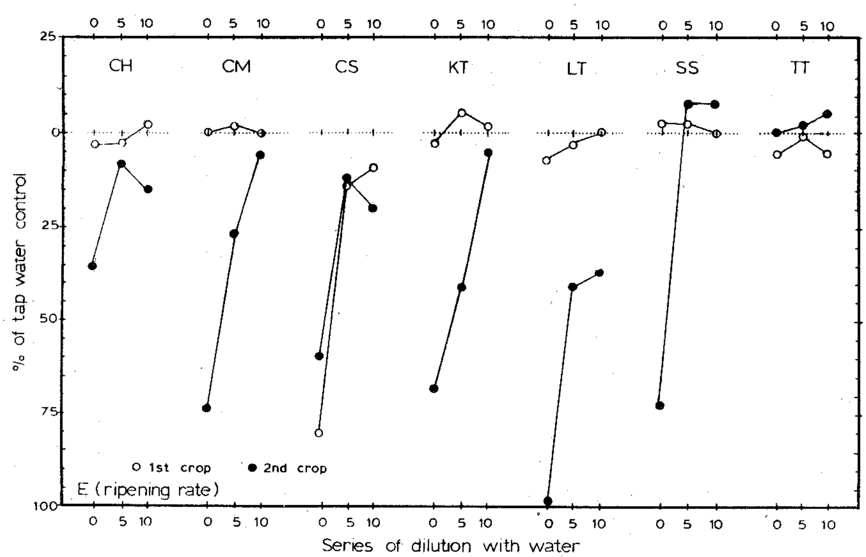

CH
CM
CS
KT
LT
SS
TT
0 5 10
25
0
25
50
75
100
% of tap water control
O 1st crop
● 2nd crop
E (ripening rate)
Series of dilution with water

Fig. 6E

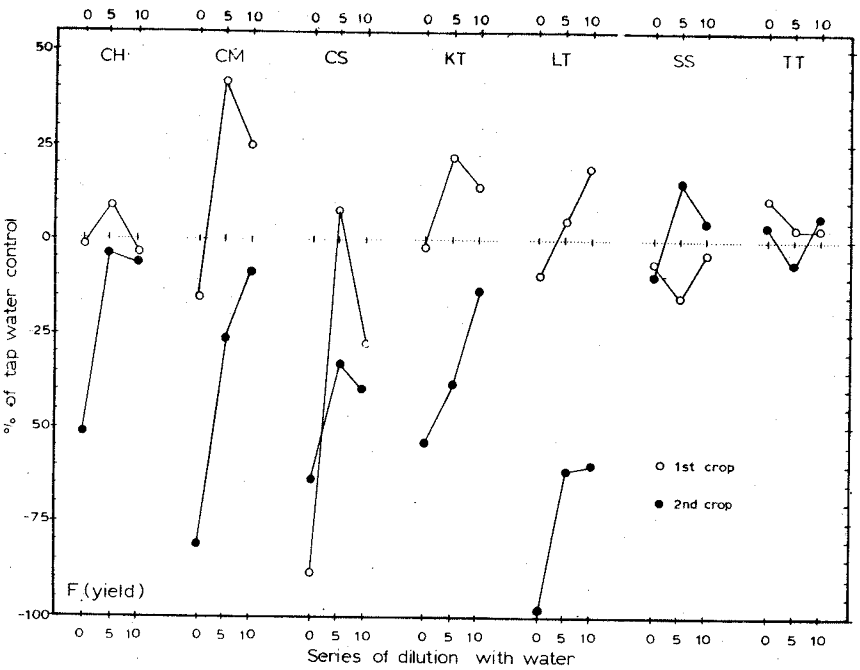


Fig. 6A-F. Comparative phytotoxic effects of 7 industrial waste waters on the growth and yield components of rice plants grown in pots in 2 crop seasons. The data were expressed as % of each measurement on that of tap water as control. Positive values indicate a stimulatory effect, while negative values indicate an inhibitory effect. The seven factories are CH (Chung-hwa), CM (Ching-mei), CS (Chia-shin), KT (Kuo-tai), LT (Lian-ta), SS (Shuang-shii) and TT (Ta-tung).
A = Effect on length of rice straw.
B = Effect on tiller numbers.
C = Effect on panicle numbers.
D = Effect on test 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).

In addition, the waste waters in a series of dilutions, namely 0 (original), 5 (diluted 5 times the amount of water in volume) and 10 (diluted 10 times) were also tested. As far as the first crop of rice was concerned, these industrial waste waters did not severely affect the rice growth, in fact, most of them exhibited a stimulatory effect on length of straw, panicle number, test weight, ripening rate and yield, except on number of tillers. In contrast, in the second crop, all aforementioned characters of rice plants were severely retarded by these industrial waste waters, resulting in a very low yield of rice at harvest. For example, although the Chia-shin water did stimulate the growth of rice plants regarding the length of straw and tiller number, the yield was significantly low. This suggests that some chemicals present in the Chia-shin water can promote the vegetative growth of rice plant, but retard the reproductive organs such as panicle initiation, resulting in a low yield. As far as the second crop was concerned, the growth and yield of rice plants were significantly retarded, this was particularly pronounced in the waters of Chia-shin, Chingmie, Kuo-tai, Lain-ta, and Shuang-shii. The reduction of rice yield affected by these industrial waters was remarkably high in the original water without dilution; however, when the waters were diluted to 5X and 10X the reduction was rapidly decreased. The yield was correlated with the yield components as mentioned. We cannot explain why these industrial waste waters significantly suppressed growth and yield of the second crop, but apparently did not affect the first crop.

It is concluded that the industrial waste waters 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 tremendous toxic effect on rice growth and yield; however, when the water was diluted the inhibition decreased. In addition, although some waters stimulated the vegetative growth of rice plant, the yield was reatrded. It is evident, therefore, that these aforementioned industrial waste waters performed detrimental rather than beneficial effects on the rice growth and yield.

Physicochemical properties of industrial waste water

Since the aforementioned seven factories released waste water which was toxic to plant growth, the causes of phytotoxicity were investigated. During eight monthly samplings of each waste water, the physicochemical properties, namely electrical conductivity (EC), pH, osmotic concentration (OC), and contents of suspended solids, Cl^-, $SO_4^=$, NH_4^+-N, and ions of Cu, Ca, Zn, Fe, Mn, K, and Na were determined. Results of the analyses are given in Table 1, where the first column shows the stantdard criteria of irrigated water for agricultural land (the data were made by a conference on Standard Criteria For Irrigation Water For Agricultural Land, Taipei, 1978). As far as the electrical conductivity was concerned, almost all waste water except Chung-hwa exhibited EC valuse much higher than the standard criterion.

Among them, the water of Lian-ta shows the highest EC value reaching above 5000 μmho/cm. The Chia-shin water also revealed the second high EC value averaging above 3600 μ mho/cm, and the Kuo-ta water was third high. However, the EC valuse fluctuated with factories and sampling times.

As far as pH was concerned, most data were within the standard criteria of pH 6.0 – 9.0, and only Ching-mei and Lian-ta waters had average values as high as 9.6, which may cause harmful effects on plant growth.

In the analyses of suspended solids, most factories showed values higher than the standard criterion and only Chung-hwa and Kuo-tai waters were below the 100 mg/l standard. The waste water from Chia-shin livestock and Shuang-shii exhibited very high suspended solid values above 600 mg/l, which of course will be dangerous to plant growth,

The Cl^- contents in the Kuo-tai and Lian-ta waters was extremely high, ranging from 548 – 1172 mg/l, but the rest of them were rather close to the standard criterion of 175 mg/l. This suggests that the phytotoxicity may partly be due to the Cl^-content.

Regarding the $SO_4^=$ contents in the waste waters, waters from Lian-ta and Ta-tung revealed higher values than standard criterion, particular in the Lian-ta water.

Table 1. *Physicochemical properties of seven industrial waste waters sampling monthly in 1978* The abbreviation of factories are: CS = Chia-shia, CM = Ching-mei, LT = Lian-ta, TT = Ta-tung, SS = Shuang-shii, CH = Chung-hwa, KT = Kuo-tai

Property	Standard criterion	Factory	Sampling date in 1978: March 15	April 20	May 17	May 17	July 12	Aug 16	Sept 19	Oct 16	Average
CL$^-$ μ mho/cm at 25°C	750	CS	2530	3110	3090	3725	3990	3857	4530	4152	3623**
		CM	3130	1690	990	3171	1220	532	2860	2330	1990**
		LT	2330	4350	1480	6130	6770	5313	6720	8093	5098**
		TT	659	612	1160	675	7220	1047	714	731	1602**
		SS	–*	1740	640	1540	1150	1870	927	2340	1457**
		CH	–*	619	333	286	–	431	450	425	424
		KT	–	2460	1120	3280	5770	1770	1760	1620	2540**
pH	6.0 to 9.0	CS	7.5	7.2	7.2	7.2	7.2	7.1	6.9	7.1	
		CM	11.8	9.5	5.8	9.7	10.3	7.6	11.6	10.3	
		LT	11.1	11.8	9.6	9.8	11.6	7.3	8.1	7.6	
		TT	6.8	5.4	9.3	7.8	2.0	6.0	5.3	5.9	
		SS	–	6.5	5.7	7.6	6.8	6.5	7.1	8.8	
		CH	–	7.8	7.5	–	6.7	6.7	7.1	7.0	
		KT	–	2.3	8.1	8.6	11.4	7.2	7.1	7.3	
Suspend solid mg/l	100	CS	283	500	550	435	530	361	1850	465	622**
		CM	124	150	27	130	410	95	128	124	149**
		LT	458	470	205	498	424	104	178	86	303**
		TT	–	–	–	–	–	–	–	–	–
		SS	–	540	140	248	232	208	94	3980	777**
		CH	–	30	30	–	16	8	4	16	17**
		KT	–	18	111	45	236	6	10	6	62
Cl$^-$ mg/l	175	CS	156	204	169	167	181	142	122	189	166
		CM	331	458	222	215	127	54	105	350	233**
		LT	614	337	339	1638	1940	814	1540	2152	1172**
		TT	343	70	181	107	151	82	130	111	147
		SS	–	480	88	223	60	118	85	234	184**
		CH	–	49	41	–	24	16	28	30	31
		KT	–	210	333	882	1340	311	367	393	548**

Table 1 cont.

Property	Standard criterion	Factory	Sampling date in 1978								Average
			March 15	April 20	May 17	June 21	July 12	Aug 16	Sept 19	Oct 16	
$SO_4^{=}$ mg/l	200	CS	120	250	40	50	30	12	23	–	75
		CM	270	150	60	43	12	24	18	23	75
		LT	345	600	70	387	533	970	605	187	452**
		TT	120	160	35	42	1360	1221	62	108	251**
		SS	–	206	158	55	110	55	83	100	110
		CH	–	250	118	–	63	129	78	116	126
		KT	–	560	55	110	190	90	125	80	173
NH_4^{+}-N mg/l	1	CS	190	333	325	318	316	336	315	373	313**
		CM	–	–	–	–	–	–	–	–	–
		LT	22	14	10	61	44	89	126	175	68**
		TT	–	–	–	–	–	–	–	–	–
		SS	–	–	–	–	–	–	–	–	–
		CH	–	–	–	–	–	–	–	–	–
		KT	–	–	–	–	–	–	–	–	–
OC m osmols	50	CS	43	64	50	44	30	57	65	54	
		CM	28	24	15	13	13	1	22	26	
		LT	36	36	15	101	85	90	96	129	
		TT	2	2	15	2	0	7	2	0	
		SS	3	47	5	15	0	29	17	42	
		CH	23	2	0	0	0	0	0	1	
		KT	34	47	11	49	59	18	17	22	

* - Without determination
** - Far beyond the standard criterion

Table 2. *Cation contents of seven industrial waste waters in the monthly samplings of 1978*

Property	Standard criterion	Factory	Sampling date in 1978								
			March 15	April 20	Apy 17	June 21	July 12	Aug 16	Sept 19	Oct 16	Average
Na^+		CS	69.5	82.5	72.5	72.9	56.5	52.0	80.5	68.3	69.3
ppm		CM	372.5	253.3	169.2	261.7	165.0	50.0	274.2	253.3	224.9
		LT	385.0	253.3	198.3	896.7	717.2	711.3	698.3	840.6	587.6
		TT	61.0	51.5	163.0	60.5	46.5	81.0	62.0	52.8	72.3
		SS	75.5	352.5	77.5	150.5	160.0	364.5	100.5	427.0	211.3
		CH	238.5	50.5	40.5	–	15.0	25.5	24.0	22.5	59.5
		KT	284.0	115.5	208.0	612.0	554.6	213.5	213.0	231.0	304.0
K^+		CS	243.0	376.5	297.8	318.4	275.3	288.4	411.5	268.5	309.9
ppm		CM	46.7	74.3	67.2	154.0	49.5	23.0	22.8	43.3	60.1
		LT	7.7	15.2	14.0	13.9	11.1	14.8	33.2	28.3	17.3
		TT	45.7	56.8	153.7	48.2	31.8	87.8	64.8	40.3	66.1
		SS	24.0	130.7	29.3	64.7	55.5	104.0	39.2	130.5	72.2
		CH	10.7	10.7	3.8	–	1.3	5.8	4.0	1.7	5.4
		KT	20.7	9.5	10.8	14.8	16.7	8.7	6.7	9.0	12.1
Cu^{++}	0.2	CS	0.40	0.18	0.19	0.17	0.07	0.98	0.07	0.20	0.28
ppm		CM	0.90	0.21	0.34	0.54	0.59	0.29	0.54	0.63	0.58
		LT	0.43	0.32	0.36	0.54	0.54	0.52	0.60	0.55	0.49
		TT	4.59	7.31	11.75	3.84	2.74	4.54	1.54	2.18	4.81
		SS	0.75	0.86	0.77	0.86	0.89	0.85	0.83	0.84	0.83
		CH	0.68	0.72	0.58	–	0.62	0.73	0.58	0.74	0.66
		KT	0.91	0.78	0.65	0.73	0.86	0.88	0.80	0.76	0.80
Ca^{++}		CS	66.3	19.5	20.2	48.6	34.3	25.4	27.4	26.1	33.5
ppm		CM	13.5	25.0	12.0	11.0	16.2	10.9	42.3	30.9	20.2
		LT	110.2	25.9	31.7	105.2	135.0	58.7	115.8	28.4	76.4
		TT	38.7	40.7	23.5	34.4	42.3	24.6	31.5	33.1	33.6
		SS	130.2	290.1	69.3	139.8	45.5	30.5	81.8	64.5	106.5
		CH	85.0	46.0	59.7	–	26.7	48.5	58.5	58.5	54.7
		KT	240.0	85.8	33.2	80.3	20.3	112.0	104.3	59.5	91.9

Table 2 . cont.

Property	Ctandard criterion	Factory	Sampling date in 1978								Average
			March 15	April 20	May 17	June 21	July 12	Aug 16	Sept 19	Oct 16	
Fe^{++}		CS	0.56	0.82	0.54	4.16	5.78	5.96	6.64	6.88	3.92
ppm		CM	0.39	1.01	1.32	1.76	1.20	2.98	1.70	1.82	1.53
		LT	1.94	1.82	1.80	0.37	0.44	0.57	0.25	0.29	0.94
		TT	0.69	2.27	0.20	0.86	1.15	1.59	0.89	1.30	1.12
		SS	1.46	1.76	1.63	1.54	1.68	1.86	1.64	1.75	1.67
		CH	0.60	0.60	0.67	–	0.95	0.86	0.76	1.20	0.81
		KT	3.01	4.93	0.52	0.09	0.42	0.59	0.81	0.62	1.37
Mn^{++}		CS	0.08	0.11	0.10	0.76	0.08	0.05	0.07	0.08	0.17
ppm		CM	0.15	0.08	0.14	0.09	0.13	0.20	0.16	0.17	0.14
		LT	0.07	0.23	0.21	0.21	0.22	0.23	0.24	0.05	0.18
		TT	0.13	0.37	0.14	0.13	0.29	0.27	0.33	0.42	0.25
		SS	0.22	0.22	0.24	0.23	0.22	0.19	0.18	0.09	0.20
		CH	0.23	0.11	0.23	–	0.22	0.15	0.22	0.13	0.18
		KT	0.43	0.58	0.22	0.21	0.13	0.11	0.43	0.23	0.29
Zn^{++}	2.0	CS	0.12	0.13	0.11	0.07	0.08	0.09	0.06	0.08	0.09
ppm		CM	0.00	0.04	0.11	0.13	0.11	0.06	0.35	0.13	0.12
		LT	0.03	0.01	0.04	0.06	0.10	0.03	0.06	0.06	0.05
		TT	0.21	2.80	2.61	0.31	5.27	4.07	3.10	4.42	2.84
		SS	1.20	0.97	1.10	1.10	0.43	0.83	1.07	1.10	0.98
		CH	2.04	0.08	0.85	–	2.07	1.34	1.09	0.75	1.17
		KT	0.50	0.22	0.09	0.10	0.04	0.08	0.08	0.08	0.15
Cr^{+6}	1	TT	18	72	5.5	9.75	0.9	27.5	0	0.6	16.6

Since it was thought that there was no ammonium product released from the factories except Chia-shin and Lian-ta, only these two factory waste waters were measured. The NH_4^+-N contents in these two waste waters exhibited extremely high values particularly in the Chia-shin water. This high amount of ammonium nitrogen tremendously promoted the vegetative growth of rice plants, but severely retarded the reproductive growth of rice plants (Figs. 6-E, C, D), resulting in very low yield (Fig. 6F). It was reported by Chou (1978) that amount of NH_4^+-N above 40 ppm in paddy soil significantly retarded rice growth.

As far as osmotic concentration was concerned, only Lian-ta water was significantly higher than 50 mosmols. Above that value there is an osmotic effect causing inhibition on plant growth.

For the monthly sampling of the waste water, it is concluded that the phytotoxicity and reduction of rice growth and yield is due primarily to electric conductivity which consists of several factors, namely suspended solid, Cl^-, $SO_4^=$, NH_4^+-N and cations. Particularly the phytotoxicity of Lian-ta water is likely due to EC, pH, suspended solid, Cl^-, $SO_4^=$, NH_4^+-N and of course, associated with osmotic concentration.

On the other hand, the cation contents of the water samplings monthly were also measured. Results of analyses are given in Table 2. As far as heavy metals, namely Cu, Zn, and Cr, were concerned, water released from Ta-tung plating factory showed significantly the highest values of these heavy metals. This indicates that the phytotoxicity and reduction of rice growth was due primarily to these heavy metals. The content of Cu in all seven factory waters was all beyond the criterion of 0.2 ppm indicating that the toxicity could partly be due to the high concentration of Cu. Regrading the sodium content in the waste water, it was found that Ching-mei, Lian-ta, and Kuo-tai exhibited high values which might possibly cause sodium toxicity to rice growth.

Furthermore, the physicochemical properties of four industrial water samples collected six times a day were also determined (Table 3). For Chia-shin factory, the EC valuse were exceedingly high, above 3513 μmho/cm on the average, and varied insignificantly with time of sampling. In Ching-mei water, the EC valuse were tremendously high at 9:00 o'clock. The sample reached 10800 μ mho/cm, and was slightly lower in the evening samples. In Lian-ta water, the EC value was also high in the day time. The EC value of Ta-tung water was significantly lower than the standard criterion. The osmotic concentrations of the four factory waters were correlated with the EC valuses. The pH valuse were almost in the range of pH 6.0–9.0 except Ching-mei waters which showed very high values (above pH 11) during the morning sampling.

Except the Ta-tung water, the content of suspended solid in the daily water samples was very high, and particularly high in the Chia-shin water (above 1000 in average, which was 10 times greater than the standard criterion). The contents of Cl^- and $SO_4^=$ significantly higher in the Lian-ta water during the day time sampling. The NH_4^+-N content was only determined in the Chia-shin water, where it varied insignificantly during the day. The dynamics of cations present in the waste waters are given in Table 4. In general, the cation content was significantly higher in the day time than in the evening. For

Table 3. *Physicochemical properties of 4 industrial waste water sampling on May 30, 1978*

Property	Factory	Sampling Time						Average
		09:00	14:00	17:00	20:00	23:00	07:00	
EC	CS	2200	3920	3900	3770	3520	3770	3513
μ mho/CM	CM	10800	1640	1220	1440	1000	4970	3512
at 25°C	LT	9430	5090	–	4240	–	–	6253
	TT	410	557	471	354	–	–	448
OC	CS	30	61	55	56	55	60	
m osmols	CM	180	17	13	15	10	65	
	LT	160	118	15	50	–	–	
	TT	0	1	0	0	–	–	
pH	CS	7.4	7.3	7.6	7.2	7.6	7.4	
	CM	11.8	10.6	9.6	9.4	10.0	11.4	
	LT	7.6	3.4	–	6.7	–	–	
	TT	7.8	6.7	7.8	6.0	–	–	
Suspend	CS	–	900	–	1580	–	670	1050
solid	CM	–	212	–	196	–	328	245
mg/l	LT	–	252	–	200	–	–	225
	TT	–	13	–	78	–	–	46
Cl^-	CS	103	187	139	175	157	234	166
mg/l	CM	695	280	139	164	72	280	272
	LT	1900	450	–	806	–	–	1052
	TT	60	132	72	43	–	–	77
$SO_4^=$	CS	11	80	16	35	–	13	31
mg/l	CM	83	38	29	38	–	–	47
	LT	1650	783	–	617	–	–	1017
	TT	57	37	57	37	–	–	47
$NH_4^{\pm}N$ mg/l	CS	–	346	–	304	–	325	325

example, the Ching-mei water exhibited high Na^+ and K^+ contents at 9:00 o'clock in the morning. The Ta-tung water had significantly higher contents of Cu, Zn, and Cr. The Cr content was particularly high in the water collected at 9:00 o'clock. The phytotoxicity caused by the Ta-tung water was likely due to the high concentration of heavy metals, such as Cu, Zn, and Cr.

Discussion

Last year we reported the study involving the Chung-hwa, Kuo-tai and Shung-shii factories. In addition to these three, we selected another four factories, namely Chia-shin (livestock), Ching-mei (dye), Lian-ta (leather), and Ta-tung (plating) to study the effects of these industrial waste waters on crop growth. It was obvious that the seven aforementioned waste waters revealed significant phytotoxic effects on the radicle growth of rice and lettuce, and also suppressed the growth and yield of rice plants grown in pots. This bioassay system has been used as a standard method to evaluate the phytotoxicity of many industrial waste waters in Taiwan (Chou, 1978; Chou *et al.*, 1978; 1979).

Table 4. *Cation contents of 4 industrial waste waters sampling on May 30, 1978*

Element (ppm)	Factory	Sampling Time						Average
		09:00	14:00	17:00	20:00	23:00	07:00	
Na^+	CS	47	84	99	73	89	95	81
	CM	1331	258	144	177	143	479	422
	LT	1113	646	241	571	–	–	642
	TT	42	49	38	21	–	–	37
K^+	CS	151	434	467	343	393	380	361
	CM	730	50	168	106	46	1006	351
	LT	21	9	10	12	–	–	13
	TT	23	50	34	18	–	–	31
Cu^{++}	CS	0.22	0.24	0.25	0.26	0.25	0.22	0.24
	CM	0.39	0.36	0.36	0.36	0.31	0.39	0.36
	LT	0.60	0.61	0.49	0.53	–	–	0.56
	TT	1.38	2.00	3.75	0.76	–	–	1.97
Ca^{++}	CS	22	22	14	30	28	51	28
	CM	12	14	13	14	14	16	14
	LT	210	186	30	86	–	–	128
	TT	42	37	40	44	–	–	41
Fw^{++}	CS	1.33	1.78	1.88	2.24	3.64	3.59	2.41
	CM	1.75	1.09	1.31	1.81	1.87	1.85	1.61
	LT	1.96	4.32	2.11	2.19	–	–	2.64
	TT	0.24	0.63	0.90	0.87	–	–	0.66
Mn^{++}	CS	0.15	0.10	0.06	0.04	0.08	0.06	0.08
	CM	0.12	0.12	0.05	0.09	0.05	0.01	0.07
	LT	0.23	0.47	0.16	0.21	–	–	0.26
	TT	0.30	0.22	0.32	0.12	–	–	0.24
Zn^{++}	CS	0.10	0.12	0.15	0.10	0.07	0.06	0.10
	CM	0.27	0.05	0.09	0.13	0.06	0.13	0.12
	LT	0.03	0.71	0.07	0.03	–	–	0.21
	TT	0.43	0.11	0.80	0.11	–	–	0.36
Cr^{6+}	CS	–	–	–	–	–	–	–
	CM	–	–	–	–	–	–	–
	LT	–	–	–	–	–	–	–
	TT**	32	30	20	28	–	–	27.5

* The data was based on water collected on June 21, 1978.

The results of the first three factories agree with those of the last year. However, the phytotoxicities varied with factories and were caused by differenct physicochemical properties. In was concluded that the order of phytotoxicity was Chia-shin > Lian-ta> Ta-tung > Kuo-tai > Shuang-shii > Ching-mei > Chung-hwa. The major cause of the phytotoxicity was high electric conductivity which reflected the amounts of suspended solid, Cl^-, $SO_4^=$, NH_4^+-N and contents of metal. For example, the toxicity of Chia-shin water apparently was due primarily to the high content of NH_4^+-N, Cl^-, and suspended solid, that of Ching-mei water was due to pH, Cl^-, Na^+, and suspended solid; Lian-ta was due to pH, suspended solid, Cl^-, $SO_4^=$, Na^+, and NH_4^+-N; Ta-tung was due to SO_4^-, Cu^{++}, Zn^{++} and Cr^{+6}; Shuang-shii was due to suspended solid, and Cl^-; Kuo-tai was due to Cl^-, Na^+, and Cu^{++}. The Chung-hwa water was shown to be the least which was difficult to correleate with these physiocochemical properties. It is likely that the toxicity of each water was not only caused by one single factor, but also by several factors together. It was also found that the toxicity was significantly higher in the day samples particularly at 7:00 and 9:00 o'clock that in the evening samples. The phytotoxicity of daily samples was also correlated with the factors mentioned.

The factories selected for this study have been established for at least five years, with their water running onto adjacent agricultural land. This has affected the texture and fertility of soils through biogeochemical processes. For example, high SAR valuse causes soil to become poor in fertility becasue of high salinity and change of the soil texture. We found that several factory waters contain significantly high amounts of Na, which caused not only sodium toxicity, but also poor soil fertility. In addition, a long term accumulation of Zn, Cu, and Cr causes soil toxcity, 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 on the land receiving the waste waters but also from the use of herbicides and pesticides by farmers. After the land has been polluted by waste waters, the fertility of soil may never return to its previous status, and naturally the agricultural productivity will be decreased (Chou, 1978, Chou *et al.*, 1978, 1979; WQS, 1969). Based on this study, we call our people's attention to the detrimental impacts of industrial waste pollutants on the ecosystem, and as their help in preserving our lands in a hgih state of productivity, thus insuring a bright future for the coming genrations.

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台灣區水汚染對農作物生產之影響
IV. 新竹及桃園地區

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本研究繼續六十七年度計劃， 從事本省新竹及桃園地區七家主要工廠排出廢水對農作物生長影響之研究，七家工廠是雙喜紙廠 (Shuang-shii)，國泰塑膠廠 (Kuo-tai), 嘉新畜牧場 (Chia-shin), 景美染整廠 (Ching-mei), 大同洋傘廠(Ta-tung)及聯大製革廠(Lian-ta) 。定期做每月採樣，其中有四天做連續每日24小時的採樣，以分析廢水中之植物毒性程度及各理化因子之程度以找尋植物毒性之原因。並以該七廠之廢水做盆栽實驗以了解廢水對水稻生育之影響。以不同生物分析的結果指出。上述各廠所排出之廢水均有强烈的植物毒性，並顯著地抑制水稻，萵苣，及裸麥草之幼根生長，其中對萵苣之毒害最大，水稻次之，裸麥草再次之。植物毒性隨工廠不同及採樣時間而異。此七家工廠廢水之植物毒性程度之秩序爲：嘉新＞聯大＞大同＞國泰＞雙喜＞景美＞中化。一般言之，白天之水樣之植物毒性較晚間者高，尤其在晨間七點及九點最高。上述廢水對盆栽之水稻生長有顯著毒害作用，特別對第二期作水稻生育更爲顯著。對水稻產量構成因子如穗數，穗重，分蘖數，結實率，千粒重及產量有顯著之抑制作用。廢水中之理化分析結果指出，上述七廠之廢水之電導度均偏高，其他如 pH 值，Cl^-, $SO_4^=$， NH_4^+-N， Na^+ ，懸浮固體含量等亦高於本省灌漑水水質標準。植物毒性之程度與上述理化因子呈正相關關係。譬如嘉新畜產場所排出之廢水之毒性與其所含氨量呈正相關，大同洋傘之廢水毒性是源於其所含之銅，鋅，鎳量過高的緣故。