IMPACTS OF WATER POLLUTION ON CROP GROWTH IN TAIWAN

III. The Detrimental Effects of Industrial Waste Waters from Plastic, Paper, and Petroleum Factories in Taiwan[1,2]

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Abstract: Waste waters coming from three factories, namely Kuo-tai (plastic), Shuang-shii (paper), and Chung-hwa (petroleum) were determined for their phytotoxicity and physicochemical properties. The effect of the waters on the growth and yield 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, lettuce, and rye grass and suppressed the root initiation of mungbeans. Lettuce was the most sensitive species to waste water, rice the second, and rye grass the least. The phytotoxicity varied with monthly sampling and with every-four-hour sampling during a day. The quality and quantity of waste waters were different among three factories. Waste water coming from Kao-tai consistently revealed the highest toxicity upon these three plants, Chunghwa the second, and Shuang-shii the least. The original waste waters from the three factories showed significant inhibition on the rice growth, resulting in decrease in straw length, tiller number, panicle number, ripening rate, testing weight, and grain yield. The physicochemical analyses of waste water revealed that the amount of suspended solids, Cl^-, SO_4^{-2}, NH_4^+-N, Na^+, Ca^{+2}, Mg^{+2}, and SAR, and the degree of electrical conductivity and osmotic concentration were significantly far beyond the standard criteria of irrigation water for agricultural land, and some of these properties would be severely detrimental to crop growth. Linear regression analyses showed that in some test waters the factors, such as electrical conductivity, suspended solid, Cl^-, SO_4^{-2}, NH_4^+-N, and some cations were significantly correlated to the phytotoxicity.

INTRODUCTION

Due to the rapid economic and industrial development in Taiwan in the last decade, the enviornmental 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

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on crop growth has been undertaken in the last few years. Not many publications dealing with this study have been reported (Chen, 1973; Chou, 1968; Chou *et al*., 1968; Yang, 1976); yet, substantial findings concerning the detrimental effects of polluted waters have appeared in journals 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). In 1977, under the auspices of JCRR, the present authors studied the area around Hsinchu area, where a vast agricultural land was jeopardized by polluted water. We, thus, focused our attention on this area and selected three major factories in this area to assess the physico-chemical nature of their waste waters and to elucidate the phytotoxic mechanisms of the polluted water. As the result of that study, we were able to make conclusion 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

Three major kinds of industrial factories around the Hsinchu area were selected for this study, these were: paper, plastic, and petroleum factories, namely the Shuang-shii, Kuo-tai, and Chung-hwa factories, respectively. To obtain as much information as possible concerning the fluctuation of the waste waters coming from the aforementioned factories, monthly sampling and every-four-hour sampling within a day were conducted. The sampling was made on the following dates on March 16, April 14, May 18, June 15, July 13, August 17, September 14, October 12, and December 16 of 1977. In addition, the every-four hour sampling within a day was also made on April 14–15, July 13–14, August 16–17, and Octobet 12–13. 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 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 plot was filled with different waste water with a series of dilutions as 10×, 100×, and 1000×, where × means dilution time. The control experiment was also set up in the same manner but with tap water instead of waste water. Three seedlings of rice varieties of Tainan 5 and Hsinchu-Ar-Chou-Chien 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 1977, respectively. Due to an accidental loss, only the results of Tainan 5 were obtained from this pot experiment. During the growth period of the rice plant, the length of the rice seedlings and number of tillerings was measured on the day at the maximum tillering stage (about the 60th day after transplanting) and on the day when plants became mature (about the 100 days after transplanting). At harvest time the length of panicle, 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:

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

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 root initiation after 6 days incubation at 25°C.

Physicochemical analysis of waters

Each aforementioned sample was determined for its pH value (Chemtrix type 40 meter), and osmotic concentration (Fiske G-66 osmometer). The cation contents present in each water sample was analyzed by an atomic absorption spectrophotometer (Perkin-Elmer Model 300). The aforementioned determination was done in the Plant Ecology Laboratory, Institute of Botany, Academia Sinica. In addition, the electrical conductivity (Conductimeter, Tacussel CO-6N), total solids, suspended solids, contedts of chloride, sulfate (Spectrophotometer, Perkin-Elmer 100), and NH_4^+-N was determined by standard methods for the examination of water and waste water (APHA, 1976) carried out in the laboratory of Taiwan Water Pollution Control Agency. In addition, sodium absorption ratio (SAR) of each water was obtained from a formula as $SAR = Na^+ \times [\frac{1}{2}(Mg^{+2} + Ca^{+2})]^{-1/2}$ (WQS, 1969).

Statistical analysis

To find out the correlation between the phytotoxicity and the physicochemical properties of each test water, a correlation analysis was made. Samples collected from each month and from every-four hr period within a day were all analyzed.

RESULTS

Phytotoxicities of industrial waste waters

In order to make a comparison of the phytotoxicity of the water among the test waters, 3 bioassays were used. From March to November 1977, waste waters from the aforementioned factories were collected monthly and were bioassayed by using lettuce, rye grass and rice as test species. Results expressed as % phytotoxicity are shown in Fig. 1. In the results of Shuang-shii water, lettuce was shown to be the most sensitive species in its response to waste water, and the phytotoxicity ranged from 25 to 40%. On the other hand, the phytotoxicity revealed by rice and rye grass were relatively lower than that by lettuce, and only a few samples were shown to have some inhibition. In general, the phytotoxicity varied with the time of sampling and was very high in the March, April, May, June and November samplings.

The Chung-hwa waste waters showed that their phytotoxicities were relatively higher than those in the Shuang-shii. Again, lettuce was the most sensitive species in its response to waste water, rye grass was the second, and rice was the least. During the 9-month periods, samples collected in March, April, July, and November exhibited significant phytotoxicity, except for the Sepıember and October samplings.

The Kuo-tai waste waters showed that their phytotoxicities were generally higher than those exhibited by the former two factory waters. Lettuce, once again, was shown to be the most sensitive species responding to the water. Although the phytotoxicities fluctuated with sampling time, it was shown that the pattern of phytotoxicity increased with the months,

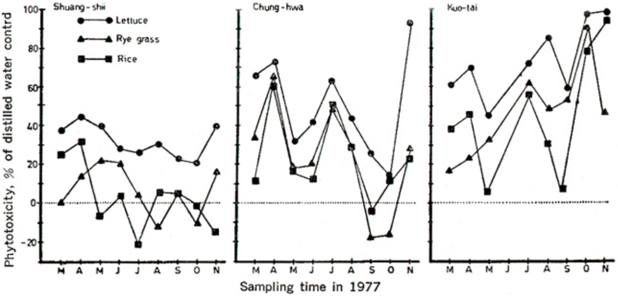

Fig. 1. The monthly phytotoxic effects of industrial waste waters from 3 factories, namely Shuang-shii, Chung-hwa, and Kuo-tai on the radicle growth of lettuce, rye grass and rice plants. The phytotoxicities were expressed as % inhibition of radicle growth against distilled water control. The negative values indicate the % stimulation.

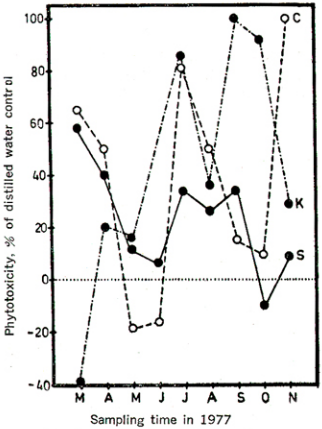

Fig. 2. The monthly phytotoxic effects of industrial waste waters from 3 factories, namely Shuang-shii (S), Chung-hwa (C), and Kuo-tai (K) on the root initiation of mungbeans. The phytotoxicity was expressed as % inhibition against distilled water control, and the negative values indicated % stimulation.

except in May and September, and the phytotoxicities of the samples collected in October and November reached almost 100% inhibition on lettuce growth.

By using mungbeans as a bioassay material, the effect of aforementioned waste waters on the root initiation of mungbeans was obtained. The results shown in Fig. 2 indicate that the phytotoxicities fluctuated during the sampling time. For waters collected in March, April, July, September, October, and November, the phytotoxicity was significantly high. The root initiation was severely damaged by some polluted waters resulting in a less number of root hairs and being dark brown in color, some damaged roots became swollen and shortened. Among the three factories, the waste waters from Chung-hwa and Kuo-tai revealed significantly higher phytotoxicities than those on Shuang-shii.

It is concluded that the phytotoxicity of industrial waters from these three factories is in the order of Kuo-tai>Chung-hwa>Shuang-shii and varied with sampling times. The phyto-

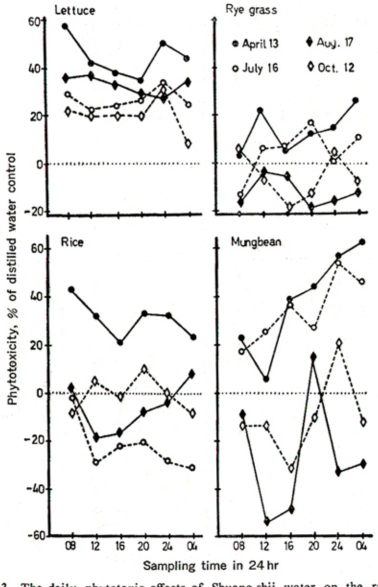

Fig. 3. The daily phytotoxic effects of Shuang-shii water on the radicle growth of rice, lettuce, and rye grass, and on the root initiation of mungbeans. The rests of description see Fig. 1.

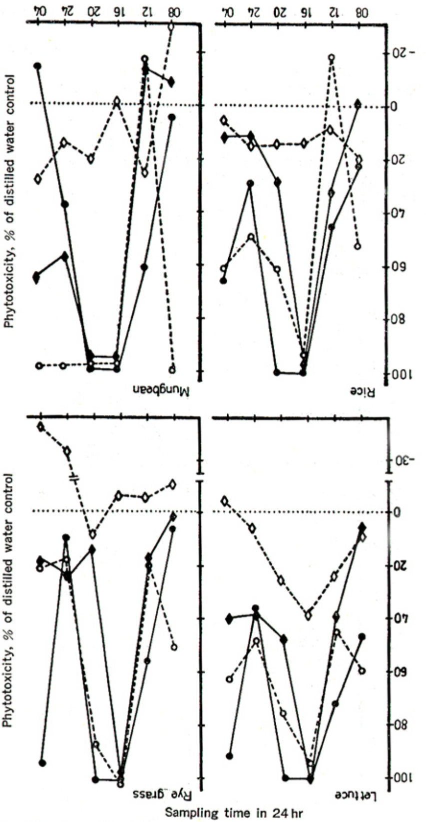

Fig. 4. The daily phytotoxic effects of Chung-hwa waste waters on the radicle growth of lettuce, rye grass, and rice and on the root initiation of mungbeans. The rests of description see Fig. 1.

toxicity of each industrial waste water is irregular and fluctuates throughout the year.

Furthermore, in order to understand the variation of phytotoxicity of each industrial waste water, water sampled at every-four hr period during the day was also examined using the same bioassay techniques. The results of the bioassay on Shuang-shii waste waters are given in Fig. 3. In all test species as shown in Fig. 3, the water collected on April 13 revealed phytotoxicities significantly higher than that on the other three sampling dates, which reflected an irregular pattern of phytotoxicity. Except for lettuce, the other test species showed considerable variation in their phytotoxicity depending on the time of sampling. This indicates that the quality of the waste water coming from the Shuang-shii factory seems to be uneven.

The waste water of Chung-hwa revealed generally higher inhibitory effects on the 4 test species than the Shuang-shii did (Fig. 4). Except for the October 12th samples, the samples

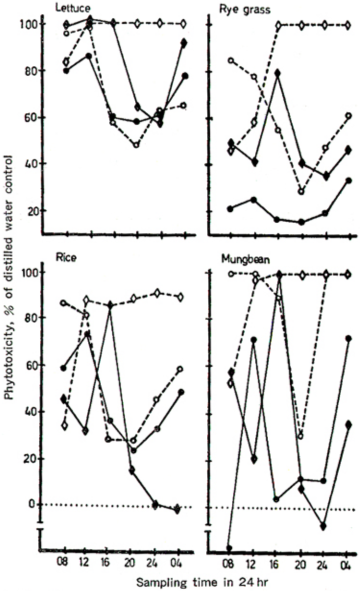

Fig. 5. The daily phytotoxic effects of Kuo-tai waste waters on the radicle growth of lettuce, rye grass, and rice, and on the root initiation of mungbeans. The rests of description see Fig. 1.

on the other 3 dates exhibited exceedingly high phytotoxicity at 16, 20 and 04 O'clock, reaching almost 100% inhibition on all 4 test species (Fig. 4).

As far as the Kuo-tai waste waters were concerned, phytotoxicities were found in three test species namely lettuce, rye grass and rice, except mungbeans. The waters sampled on October 12 exhibited extremely high inhibition, nearly 100% inhibition, except for the sample collected at 8 O'clock (Fig. 5). The water samples collected on April 13 exhibited relatively low inhibition on the radicle growth of 3 species and particularly on the rye grass. The deleterious effects of industrial waste water on the root initiation of mungbeans seem to be obvious that some seedlings die one day after the treatment of the waste water. In addition, the radicle growth of rice, lettuce and rye grass seedlings were abnormal as they grew in the test waters. The radicles became short, dark brown in color, and fragile, and had fewer root hairs as compare with seedlings growing in distilled water.

It is concluded based on nine months of sampling that the phytotoxicity in general varied with the sampling time and is likely irregular; however, the order of phytotoxicity is Kuo-tai>Chung-hwa>Shuang-shii. In addition, the toxicity of 24-hr sampling (every-four hr during a day) shows that the waters from these three factories also differ from each other. The waters collected during the night seems to be more highly toxic than that in the day. This is particularly true in waters from the Chung-hwa and Kuo-tai factories.

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

The waste waters continuosly collected from the aforementioned three factories were used to irrigate rice plant (Tainan 5) grown in clay pots. This experiment was carried out during the second crop season of 1977. Measurements were taken on September 14, and October 12, 1977. The results of root and straw measurements based on their dry weights were obtained, and the phytotoxicity was expressed as % inhibition of root and straw growth of test waters

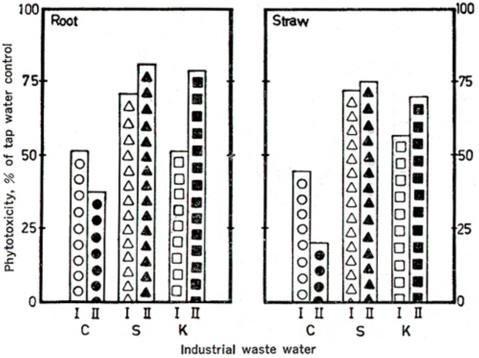

Fig. 6. The phytotoxic effects of industrial waste waters from 3 factories namely Chung-hwa (C), Shuang-shii (S), and Kuo-tai (K) on the growth of rice plants grown in pots; and with two measurements on September 14 (I), and October 12 (II). The phytotoxicities were expressed as % inhibition of tap water control.

against that of tap water which served as the control (Fig. 6). It was shown that the waste waters from these three factories exhibited significant inhibition on the root and straw growth. The order of toxicity was Kuo-tai>Shuang-shii>Chung-hwa. The root growth was severely reduced by 30-80%, while the straw growth was reduced by 20-75%. Furthermore, during the harvest, the yield components of the rice growth were also obtained (Fig. 7). The numbers of tillers and panicles of the rice plants grown in Chung-hwa water were significantly higher than those in tap water, Shuang-shii or Kuo-tai water; however, the ripening rate, grain weight and yield were all lower than those grown in water which served as control. Obviously, all parts of the yield components of rice plants grown in Kuo-tai and Shuang-shii waters were significantly lower as compared to plants grown in tap water. Furthermore, since the rice seedlings died in the Kuo-tai waste water, nothing could be measured at sampling time. It is concluded that the Chung-hwa exhibited the least toxicity, Shuang-shii was the next, and Kuo-tai the highest. These results are not in full agrement with the previously reported findings from our bioassay studies. Needless to say, when the growth of the rice plants was affected by pollutants, the yield was severely affected.

In conclusion, the Kuo-tai water exhibited the highest detrimental effect on rice growth, the Shuang-shii was the next, and the Chung-hwa was the least regarding to the pot experiments.

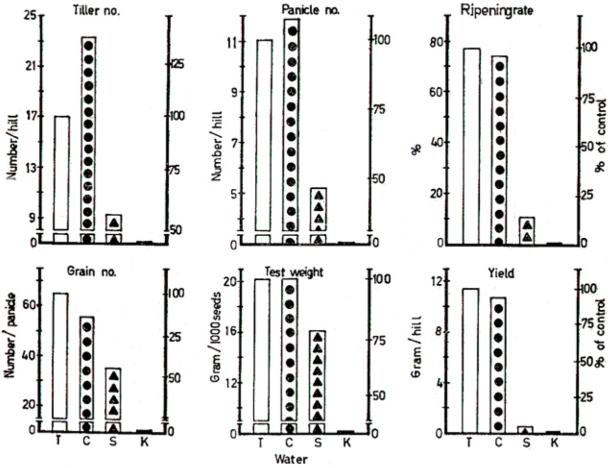

Fig. 7. The effects of tap water (T), and 3 industrial waste waters, namely Chung-hwa (C), Shuaug-shii (S), and Kuo-tai (K) on the growth and yield components of rice plants at harvest.

Physicochemical properties of industrial waste waters

Since the aforementioned three factories released waste water which were phytotoxic to plant growth, the cause of phytotoxicity was investigated. During nine months of sampling of each of the waste water, the physicochemical characteristics, namely electrical conductivity, pH, and contents or suspended solids, Cl^-, SO_4^{-2}, NH_4^+-N, osmotic concentration, and ions of Cu, Zn, Ca, Mg, Fe, Na and Mn were determined. Results of the analyses are given in Table 1, where the first column shows the standard criteria for irrigated water for agricultural land, which were made by a recent conference on standard criteria for irrigation water for agricultural land (Taipei, 1978). It is obvious from the results that most data from waste waters exceeds the standard criteria and indicates the harmful effects of waste water on crop growth. As far as electrical conductivity was concerned, only one of the samples of June 15th collected from Chung-hwa revealed lower than the standard criteria. The average data of electrical conductivity of these three waters was tremendously above the standard criteria, and particularly the Kuo-tai water was extremely high of 5715.38 μmhos/cm at 25°C, the Chung-hwa was the next high of 4347.8 μmhos/cm at 25°C, and Shuang-shii the lowest of 185 μmhos/cm at 25°C. As pH values were concerned, most data were within the criteria pH 5.0-9.0, and about one third of samples beyond the criteria. The Chung-hwa waters revealed significantly higher pH values and only two samplings were in the safety range.

So far as suspended solids were concerned, about two-thirds of the samples exceeded the criteria of 100 mg/l, particularly, Shuang-shii waters were all above the criteria. With regard to Cl^- contents, it was very variable and about one half of the samples were beyond the standard, furthermore, all Kuo-tai waters exceeded the standard. Concerning the SO_4^{-2} content in the waste waters, the Chung-hwa water exhibited generally higher than that of the other two factories and more than one half of samples exceeded the standard criteria. The NH_4^+-N content of waste water varied with times of sampling, and some showed very high concentrations. As for the osmotic concentration, the values were generally as low as 50 milliosmols except that several samples exceeded the standard criteria. The contents of heavy metals, namely Zn and Cu were all below the standard criteria. The contents of remaining cations varied very much with time of samplings, and the Na^+ content was relatively higher in the Kuo-tai water than from the other two factories.

It is concluded that the phytotoxicity of Shuang-shii water is due primarily to its electrical conductivity, and partially due to its suspeuded solids, total solids, chloride, and magnesium content; the phytotoxicity of Chung-hwa water is due to electrical conductivity, pH, total solids, and SO_4^{-2} content, Chung-hwa water revealed significantly higher amount than the other, and showed high peaks at 12:00 and 20:00 O'clock which also agreed with the phytotoxicity pattern of the bioassay findings. Referning to the amount of NH_4^+-N present in the waste waters, most samples exceeded the standard criteria and the Chung-hwa water revealed distinguishingly higher amount than the other two. At 12:00, 20:00, and 04:00 O'clock, the quantity of NH_4^+-N present in Chung-hwa water was significanlty higher which also coincided with the phytotoxicity pattern as previously described. The osmotic concentration of waste water was relatively low and the values were near the safety range of the standard, although two samples from Kuo-tai factory gave relatively high readings of about 100 milliosmols, at which level the radicle growth of lettuce would be seriously affected. The cations of Cu^{+2}, Zn^{+2}, Ca^{+2}, Mg^{+2}, Fe^{+2}, Na^+, and Mn^{+2} (Table 2) were all below the standard criteria and so were not the cause of phytotoxicity; however, the data of SAR obtained from cations of Ca, Mg, and Na suggests that some phytotoxicities present in the Shuang-shii water were due to sodium toxicity.

Correlation analyses between phytotoxicity and physicochemical properties

In order to understand phytotoxicities of waste waters in correlation to each physicochemical properties analyzed, correlation coefficients were obtained by using linear regression

Table 1. Physicochemical properties of 3 industrial waste waters during a monthly sampling in 1977

Physicochemical property	Standard criteria	Sampling date in 1977									Average
		Mar. 16	Apr. 14	May 18	June 15	July 13	Aug. 17	Sept. 14	Oct. 12	Nov. 16	
Electrical conductivity (μ mhos/cm at 25°C)	750(1)										
S		1461	2284	1370	1210	2330	1913	1960	2683	1450	1851.0
C		7984	2930	1200	692	16600	3060	1000	1384	4280	4347.8
K		2334	4132	1800	—	5660	8280	8050	11867	3600	5715.38
pH	5.0-9.0(1)										
S		9.8	8.2	9.7	7.1	6.8	8.6	8.2	6.9	7.2	8.06
C		9.4	7.2	10.0	9.6	12.2	11.5	9.2	8.4	11.6	9.90
K		8.3	9.5	7.2	—	7.5	6.8	8.8	1.8	8.5	7.30
Suspend solide (mg/l)	100(1)										
S		1060	677	508	624	—	543	540	778	664	674.25
C		180	40	15	120	573	124	—	28	58	142.25
K		69	134	34	—	121	39	82	82	344	113.13
Total solid (mg/l)											
S		2944	3486	2400	2150	3710	3603	3200	2977	3320	3087.78
C		5349	1796	776	986	10300	1450	762	1441	2260	2790.00
K		1520	2870	1360	—	3600	6013	6130	4823	2730	2546.22
Cl^- (mg/l)	175(1)										
S		116	278	162	38	336	173	194	312	136	193.89
C		2546	174	64	66	89	26	58	101	74	355.33
K		630	1189	410	—	1820	2913	3060	2035	1120	1647.13
SO_4^{-2}	200(1)										
S		180	125	165	190	110	147	135	99	125	141.78
C		480	636	180	150	450	209	160	195	680	348.89
K		125	171	330	—	300	253	400	1570	144	411.63
NH_4^+-N (mg/l)	1(1)										
S		7.5	8.1	10.5	12.0	—	11.5	9.8	27.3	5.5	11.53
C		91.0	82.2	3.0	1.5	1.75	0.6	1.0	10.2	12.0	22.58
K		0.2	2.2	0.05	—	0.6	6.63	0.1	28.0	21.0	7.35
OC (mosmol)	50(2)										
S		22	42	22	17	41	39	35	59	20	33.00
C		139	36	9	5	71	51	10	12	43	41.78
K		34	61	23	—	170	172	150	129	58	99.63
Cu^{+2} (mg/l)	0.2(1)										
S		0.04	0.06	0.04	0.01	0.02	0.15	0.01	0.02	0.00	0.04
C		0.02	0.03	0.05	0.01	0.03	0.02	0.01	0.01	0.01	0.02
K		0.03	0.02	0.05	—	0.03	0.08	0.05	0.03	0.01	0.04

Table 1. Physicochemical properties of 3 industrial waste waters during a monthly sampling in 1977 (continued)

Physicochemical property		Standard criteria	Sampling date in 1977									Average
			Mar. 16	Apr. 14	May 18	June 15	July 13	Aug. 17	Sept. 14	Oct. 12	Nov. 16	
Zn^{+2} (mg/l)		2.0[1]										
	S		0.06	0.08	0.12	0.08	0.09	0.15	0.08	0.13	0.07	0.10
	C		0.00	0.14	0.04	0.00	0.02	0.02	0.03	0.20	0.03	0.03
	K		0.02	1.17	0.07	—	0.02	0.10	0.02	0.05	0.04	0.19
Ca^{+2} (mg/l)												
	S		104.6	41.4	21.9	19.9	2.0	6.6	83.4	36.4	11.0	36.36
	C		24.4	63.7	41.2	26.3	32.2	43.1	67.2	71.5	48.4	46.44
	K		42.2	85.2	78.4	—	771.8	126.5	154.2	102.5	101.8	182.83
Mg^{+2} (mg/l)												
	S		8.2	10.0	7.8	7.0	8.7	9.2	12.8	416.7	290.0	85.60
	C		57.0	11.5	5.0	7.8	0.01	1.87	10.2	233.0	210.0	59.60
	K		19.2	10.7	19.8	—	19.3	27.4	53.6	200.0	130.0	60.00
Fe^{+2} (mg/l)												
	S		0.23	0.14	0.13	0.17	0.33	0.54	0.71	0.35	0.47	0.34
	C		0.15	0.61	0.03	0.00	0.04	0.03	0.13	0.75	0.02	0.19
	K		0.14	0.05	0.09	—	0.64	0.09	0.00	4.90	0.30	0.78
K^{+} (mg/l)												
	S		32.6	37.6	24.6	36.4	52.2	37.5	39.0	132.2	48.3	48.93
	C		8.0	3.6	5.4	3.4	5.6	4.8	4.4	6.0	16.9	6.46
	K		5.8	6.6	4.6	—	14.3	12.2	54.3	213.5	17.6	41.11
Na^{+} (mg/l)												
	S		164	236	96	176	299	237	216	274	360	228.67
	C		720	117	82	32	98	91	280	243	1240	322.56
	K		87	241	54	—	1373	176	1110	1512	930	685.38
Mn^{+2} (mg/l)												
	S		0.24	0.22	0.12	0.12	0.22	0.29	0.37	0.15	0.02	0.19
	C		0.07	0.34	0.04	0.00	0.01	0.00	0.00	0.00	0.05	0.06
	K		0.00	0.03	0.00	—	0.01	0.14	0.00	0.70	0.00	0.11
SAR												
	S		4.15	8.55	4.44	8.60	20.31	13.92	5.80	2.79	4.45	4.69
	C		8.09	3.53	3.21	1.41	4.79	3.66	8.40	3.12	17.06	7.34
	K		2.78	6.55	1.41	—	13.32	3.68	19.54	19.92	14.34	11.20

The abbreviations of factories are given as follows: S= Shuang-shii, C= Chung-hwa, K=Kuo-tai

(1) Standard criteria for irrigation water for agricultural land in Taiwan.

Table 2. Physicochemical properties of 3 industrial waste water collected within a day

	Standard criteria	Sampling on April 14-15, 1977						Average
		8:00	12:00	16:00	20:00	24:00	04:00	
EC (μ mhos/cm)	750[1] 2250[3]							
S		1690	2554	1954	2164	2702	2363	2284
C		2145	4038	2860	3884	2112	2541	2930
K		3481	7074	2677	2996	2728	5833	4132
pH	5.0-9.0[1]							
S		8.2	6.7	10.1	7.0	7.7	9.6	8.2
C		11.1	7.5	2.7	3.0	9.1	9.6	7.2
K		11.4	12.0	8.5	8.3	8.2	8.3	9.5
Suspend solid (mg/l)	100[1]							
S		609	366	820	800	600	865	677
C		40	32	97	20	26	27	40
K		149	142	110	160	184	58	133.8
Total solid (mg/l)								
S		3410	2905	3636	3066	4098	3800	3485.8
C		1338	2392	1788	2303	1406	1550	1796.2
K		2964	4946	1935	2332	1847	3464	2869.7
Cl^- (mg/l)	175[1] 350[3]							
S		108	517	86	550	204	204	278.2
C		54	366	97	270	75	183	174
K		873	2134	733	808	765	1822	1189.2
SO_4^{-2} (mg/l)	200[1] 576[3]							
S		90	140	150	140	150	80	125
C		640	780	650	760	535	450	635.8
K		180	225	145	165	140	170	170.8
NH_4^+-N (mg/l)	1[1]							
S		5.8	5.8	5.0	3.0	10.5	18.3	8.1
C		5.2	240.0	2.5	162.0	3.2	8.0	82.2
K		0.5	0.6	4.1	3.0	2.6	2.4	2.2
OC (mosmols)	50[2]							
S		32	34	43	29	57	58	42.2
C		24	53	28	48	29	34	36.0
K		45	99	39	40	40	103	61.0
Cu^{+2} (mg/l)	0.2[1]							
S		0.08	0.04	0.07	0.09	0.03	0.02	0.06
C		0.03	0.07	0.04	0.03	0.01	0.02	0.03
K		0.01	0.01	0.04	0.02	0.03	0.01	0.02
Zn^{+2} (mg/l)	2.0[1]							
S		0.01	0.04	0.00	0.01	0.01	0.00	0.01
C		0.00	0.03	0.40	0.36	0.04	0.01	0.14
K		0.01	0.04	0.00	0.01	0.01	0.00	0.07
Ca^{+2} (mg/l)								
S		0.11	0.03	0.07	0.02	0.13	0.10	0.08
C		25.7	59.4	85.4	28.4	20.0	29.4	41.38
K		42.2	41.1	190.5	66.4	97.8	61.0	85.15
Mg^{+2} (mg/l)								
S		8.8	14.4	5.8	12.8	10.0	8.4	10.03
C		2.2	19.8	20.4	12.4	1.6	12.4	11.50
K		1.2	0	17.2	16.4	15.6	14.0	10.73
Fe^{+2} (mg/l)								
S		0.23	0.19	0.07	0.02	0.29	0.02	0.14
C		0.00	0.03	1.60	1.98	0.02	0.04	0.61
K		0.03	0.08	0.04	0.03	0.00	0.13	0.05

Table 2. Physicochemical properties of 3 industrial waste water collected within a day (continued)

	Standard criteria	Sampling on April 14-25, 1977						Average
		8:00	12:00	16:00	20:00	24:00	04:00	
K^+ (mg/l)								
S		36.8	26.6	20.0	18.0	63.2	60.9	37.60
C		3.4	3.9	3.0	4.5	3.0	3.9	3.62
K		5.0	9.4	5.2	4.8	4.6	10.5	6.58
Na^+ (mg/l)	1300(3)							
S		234	170	312	80	292	382	236
C		147	56	98	78	164	156	116.5
K		148	420	108	190	124	456	241.0
Mn^{+2} (mg/l)								
S		0.17	0.16	0.10	0.23	0.42	0.25	0.22
C		0.00	0.65	0.57	0.80	0.00	0.06	0.34
K		0.00	0.00	0.04	0.04	0.10	0.12	0.03
SAR*	4							
S		16.68	9.60	27.68	4.76	19.53	27.68	17.66
C		7.52	1.13	2.46	3.06	9.51	6.06	4.96
K		6.13	18.08	2.01	5.40	3.06	13.67	8.06

The abbreviations of factories are given as follows: S= Shuang-shii, C=Chung-hwa, K=Kuo-tai
* SAR=Sodium absorption ratio, the value of SAR exceeds 4 will injury to plant growth.
(1) Standard criteria for irrigation water for agricultural land in Taiwan.
(2) The osmotic concentration of solution exceeds 50 milliosmols will injury to plant growth.
(3) The standard criteria above the indicated values will severely injury to plant growth.

analysis. The data of correlation coefficient between phytotoxicities on three test species against waste water from three factories and each of the properties are given in Table 3. In Shuang-shii waters, only the phytotoxicity revealed from lettuce was significantly correlated with the NH_4^+-N content at 5% level of confidence. In the Chung-hwa waters, the phytotoxicity revealed from lettuce was significantly correlated with the contents of SO_4^{-2}, K^+, while inhibition was insignificantly correlated with the remaining factors. In the Kuo-tai waters, the phytotoxicity on lettuce was sufficiently correlated with NH_4^+-N content; the phytotoxicity on rye grass was significantly correlated with electrical conductivity, pH, osmotic concentration, and the contents of SO_4^{-2}, Fe^{+2}, K^+, Na^+, and Mn^{+2}; furthermore, the toxicity on rice growth was correlated with total suspended solids. This analysis was performed by linear regression, thus. other factors may also be responsible for phytotoxicity although they were shown to be insignificant correlated linearly.

Furthermore, to understand the cause of phytotoxicity fluctuation within a single day tests were seen on April 14–15, 1977, the same analysis was also performed, and results of analysis were obtained (Table 4). With regard to the Shuang-shii waste water, the phytotoxicity on rye grass was significantly correlated with electrical conductivity (Table 4, second column). Regarding the Chung-hwa waste water, the phytotoxicities on rice plants were obvious and linearly correlated with pH, and the contents of Zn and Fe. As far as Kuo-tai waters were concerned, it was more obvious that the phytotoxicity on lettuce was significantly correlated with electrical conductivity, the contents of total solids, SO_4^{-2}, NH_4^+-N, Cu and Mg. The phytotoxicity on rye grass was significantly correlated with osmotic concentration, and amount of Fe, K, and Na, where the phytotoxicity on rice was also significantly correlated with pH, total solids, SO_4^{-2}, NH_4^+-N, and Mg^{+2}.

The aforementioned correlations indicate that the phytotoxicity was linearly correlated with

Table 3. Correlation coefficients between phytotoxicity and physicochemical property of each water. The waters were collected within a 9-month period from 3 factories, and the phytotoxicities of each water were revaled from 3 test species

Properties	Shuang-shii			Chung-hwa			Kuo-tai		
	Lettuce	Rye grass	Rice	Lettuce	Rye grass	Rice	Lettuce	Rye grass	Rice
EC	0.425	0.550	0.109	0.474	0.507	0.501	0.546	0.773*	0.205
pH	0.511	0.007	0.007	0.283	0.122	0.389	0.447	0.784*	0.334
Total solid	0.005	0.532	0.129	0.397	0.498	0.144	0.387	0.201	0.061
Total suspend solid	0.108	0.129	0.476	0.215	0.383	0.403	0.556	0.053	0.735*
Cl^-	0.249	0.036	0.145	0.230	0.281	0.201	0.320	0.571	0.300
SO_4^{-2}	0.331	0.317	0.309	0.886*	0.685	0.520	0.397	0.819**	0.316
NH_4^+-N	0.711*	0.425	0.184	0.452	0.550	0.304	0.845**	0.463	0.430
OC	0.070	0.620	0.046	0.530	0.466	0.180	0.120	0.713*	0.029
Cu^{+2}	0.170	0.556	0.230	0.410	0.452	0.446	0.100	0.058	0.677
Zn^{+2}	0.140	0.346	0.212	0.670	0.165	0.210	0.060	0.390	0.032
Ca^{+2}	0.070	0.130	0.060	0.160	0.267	0.482	0.080	0.319	0.134
Mg^{+2}	0.280	0.212	0.230	0.226	0.368	0.242	0.653	0.329	0.690
Fe^{+2}	0.490	0.340	0.218	0.630	0.096	0.200	0.313	0.790*	0.506
K^+	0.030	0.109	0.191	0.785*	0.031	0.167	0.477	0.740*	0.391
Na^+	0.200	0.123	0.134	0.730*	0.006	0.225	0.480	0.855**	0.527
Mn^{+2}	0.290	0.401	0.419	0.160	0.652	0.642	0.440	0.763*	0.417

df=7 * 5%=0.666 ** 1%=0.798

df=9 * 5%=0.707 ** 1%=0.834

Table 4. Correlation coefficients between phytotoxicity and physicochemical property of each water. The waters were collected in every-4-hr sampling during April 14–15, 1977 from 3 factories. The phytotoxicities were obtained from each water against 3 test species

Properties	Shuang-shii			Chung-hwa			Kuo-tai		
	Lettuce	Rye grass	Rice	Lettuce	Rye grass	Rice	Lettuce	Rye grass	Rice
EC	0.160	0.840*	0.594	0.562	0.540	0.494	0.820*	0.759	0.796
pH	0.440	0.140	0.024	0.735	0.731	0.899*	0.519	0.104	0.881*
Total solid	0.370	0.031	0.031	0.547	0.717	0.501	0.854*	0.604	0.848*
Total suspend solid	0.350	0.083	0.157	0.320	0.281	0.399	0.289	0.708	0.221
Cl	0.538	0.433	0.117	0.424	0.431	0.263	0.774	0.787	0.747
SO_4	0.488	0.233	0.250	0.208	0.125	0.239	0.844*	0.365	0.853*
NH_4-N	0.230	0.666	0.377	0.240	0.337	0.175	0.860*	0.339	0.810*
OC	0.320	0.433	0.548	0.381	0.393	0.281	0.747	0.887*	0.680
Cu^{+2}	0.450	0.779	0.403	0.260	0.197	0.100	0.810*	0.621	0.646
Zn^{+2}	0.760	0.128	0.098	0.690	0.671	0.890*	0.670	0.040	0.656
Ca^{+2}	0.492	0.395	0.188	0.500	0.474	0.254	0.387	0.030	0.492
Mg^{+2}	0.190	0.437	0.408	0.317	0.768	0.667	0.870*	0.227	0.898*
Fe^{+2}	0.740	0.210	0.589	0.713	0.686	0.895*	0.580	0.875*	0.014
K	0.550	0.447	0.056	0.496	0.474	0.350	0.688	0.901*	0.620
Na	0.250	0.053	0.485	0.520	0.474	0.486	0.380	0.858*	0.590
Mn^{+2}	0.016	0.293	0.119	0.676	0.632	0.713	0.340	0.452	0.468

df=4 * 5%=0.811 ** 1%=0.917

the properties analyzed, but the results did not imply that the properties which exhibited an insignificant correlation coefficient at 5% level were not causes of phytotoxic mechanism because in some cases the amount was exceedingly higher than the standard criteria. In other words, some physical chemical properties may cause phytotoxicity on plants without performing a linear correlation.

DISCUSSION AND CONCLUSION

From the results of this study, it was obvious that the three aforementioned waste waters exhibited significant phytotoxic effects on the radicle growth of rice, rye grass, and lettuce, and suppressed the root initiation of mungbeans. 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). The results of this bioassay method agrees with those of previous studies in that the lettuce was the most sensitive species to waste waters, rice the second, and rye grass the least. However, the phytotoxic pattern of mungbeans responding to waste waters seems to be different from that by lettuce, rice and rye grass. Since there was a difference in phytotoxicity of the waste waters from these factories, the quality and quantity of these waters were different. Among the three factories, water coming from Kuo-tai consistently revealed the highest toxicity upon the three test species. Furthermore, the Kuo-tai water when used in pot experiments caused the death of rice seedlings within a few days of transplanting and showed tremendous toxic effects on rice growth. In the Maioli and Hsinchu areas, a vast agricultural land was severely jeopardized by industrial waste water resulting in a great reduction of agricultural productivity, particularly for the rice crop. The local farmers always claim that the reduction of productivity was due primarily to the industrial waste waters coming from the adjacent factories. Analyses in this experiment indicate that most of the samples correlated during this study showed that their physicochemical properties were far above those outlined as standard criteria in the recent conference on "Standard Criteria For Irrigation Waters For Agricultural Land in Taiwan" (1978). It was evident that the physicochemical properties, such as electrical conducitivity, suspended solids, Cl^-, SO_4^{-2}, NH_4^+-N, osmotic concentration, and some cations, and SAR present in many samples exceeded the standard criteria. Furthermore, a significant linear correlation was found between phytotoxicity and physicochemical nature in the waste waters examined. This indicates that the phytotoxicity was due primarily to the factors correlated.

The factories selected for this study have been established for at least 5 years, with their waste waters running onto their adjacent agricultural lands has affected the texture and fertility of soils through biogeochemical processes. For example, high SAR values will cause soil to become poor in fertility because of high salinity and change of the soil texture. A long term accumulation of cations, such as Cu, Zn, and others may also cause soil toxicity, resulting in detrimental effect on plant growth. The unique chemical wastes released from a factory may significantly 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 from adjacent factories 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; WQS, 1969). Based on this study, we should like to call our people's attention to be aware of the detrimental impacts of industrial waste pollutants on the ecosystem, and to preserve our lands in a high state of productivity; thus insuring a bright future for the coming generations.

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