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IMPACTS OF WATER POLLUTION ON CROP GROWTH IN TAIWAN

II. Phytotoxic Natures of Six Rivers and Twenty Seven Industrial Waste Waters in Kaohsiung Area, Taiwan(1, 2)

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Abstract

This study was aimed to evaluate the phytotoxic natures of polluted waters coming from six rivers and 27 industrial waste waters in Kaohsiung area, Taiwan. Results were shown that among three test plants namely lettuce, rice and rye grass, lettuce was each time the most sensitive to polluted waters and was sharply different from the other two species, rice was the second, and rye grass was the least affected. The order of phytotoxicity reflected from the water of six rivers is follows: Chien-Cheng-Ho>Jen-Ai-Ho>Ar-Kong-Ten-Chi>Ten-Paw-Chi>Hou-Ching-Chi>Ning-Yuan-Chun. There was a vast area of agricultural land which borders Hou-Ching-Chi where many crops, such as rice, cabbage, turnip, and trapa were severely jeopardized. The grain yield of rice along this river was reduced by at least 40%, and the number of tiller, panicle, and test weight were greatly reduced. The phytotoxicity in the waters of Ar-Kong-Ten-Chi, Chien-Cheng-Ho, Jen-Ai-Ho and Ten-Paw-Chi was correlated with electrical conductivity; furthermore, the phytotoxicity of the first three was also correlated with osmotic concentration. Two river waters of Ar-Kong-Ten-Chi and Hou-Ching-Chi showed their phytotoxicity being correlated with NH_4^+-N content. The phytotoxicity of 27 industrial waste waters varied with factory, thus factories Ta-Nun, Chung-Yu-Chu-Yun, Chung-Chien, and Swan-Lu exhibited inhibition higher than 75% of phytotoxicity in all test species. However, the phytotoxicity was poorly correlated with the physicochemical properties as studied, and the cause was discussed.

Introduction

Due to the rapid economic and industrial development in Taiwan in the

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last decade, the environmental impact has become a severe problem. Many factories have been established during these past few years resulting in a great quantity of both air and water pollutants. That pollutants cause severe injury to living organisms has been reported from many parts of the world (Chou, 1978a; Chou, 1978b; Chuang, 1973; Haw, 1975; Hindawi, 1970; Hsu, 1975; Hung *et al.*, 1975, 1977; Giese and Christensen, 1954; Jeng *et al.*, 1973a, 1973b, Rich, 1964; Levitt, 1972; Liu, 1977; Su *et al.*, 1975, 1977). In Taiwan, the investigation of the impact of polluted waters on crops has scarcely begun. However, during the past five years many agricultural lands in Taiwan, and particularly the rice paddy fields have been polluted by waters coming from adjacent factories. The total area of polluted rice fields has increased from year to year extending from northern Taiwan to the south. In 1975 a pilot project on the environmental pollution control in Taiwan was organized by the National Health Administration of Taiwan to assess the nature of the biological, chemical, and physical pollutants. The first stage of this pilot project was carried out in the Kaohsiung area, in southern Taiwan, where a vast area of rice fields was jeopardized by polluted water. The grain yield of the rice as well as of other crops has been reduced (Chou *et al.*, 1978). This study was therefore aimed at evaluating the phytotoxic nature of the waters from six rivers and the industrial wastes from 27 factories along Hou-Ching-Chi in the Kaohsiung area.

Materials and Methods

Study area and sampling stations

In the Kaohsiung area six rivers were selected, namely Ar-Kong-Ten-Chi, Chien-Cheng-Ho, Hou-Ching-Chi, Jen-Ai-Ho, Ning-Yuan-Chun, and Ten-Paw-Chi. Stations along each river were located for sampling; these are designated A_0 to A_5 for Ar-Kong-Ten-Chi, C_1 to C_4 for Chien-Cheng-Ho, F_1 to F_{10} for Hou-Ching-Chi, L_1 to L_{10} for Jen-Ai-Ho, N_1 to N_4 for Ning-Yuan-Chun, and T_1 to T_6 for Ten-Paw-Chi (Fig. 1). The designated symbols will be used for the sampling stations throughout the text except where otherwise stated. Since a large area of paddy fields along Hou-Ching-Chi was jeopardized by polluted water, twenty seven factories along this river were also selected for investigation. These factories include Chang-Chun, Chien-Shun, Chieng-Chung, Chou-Chi-Electronic, Chung-Chien, Chung-Hua, Chung-Yu, Chung-Yu-Chu-Yun, Far-East, Feng-Shi-Ta, Fu-Lu, Hun-Kuo, Jeng-Ko-Wei, Jeng-Ta, Kao-Nan, Li-Ching, Lien-Tai, Shan-Yeh, Swan-Lu, Ta-Cheng-Chang-Cheng, Ta-Ming Battery, Ta-Nun, Ta-Teh-Chang, Tung-Chien, Tung-I, Yung-Sing-Chemical, and Tung-Yuan.

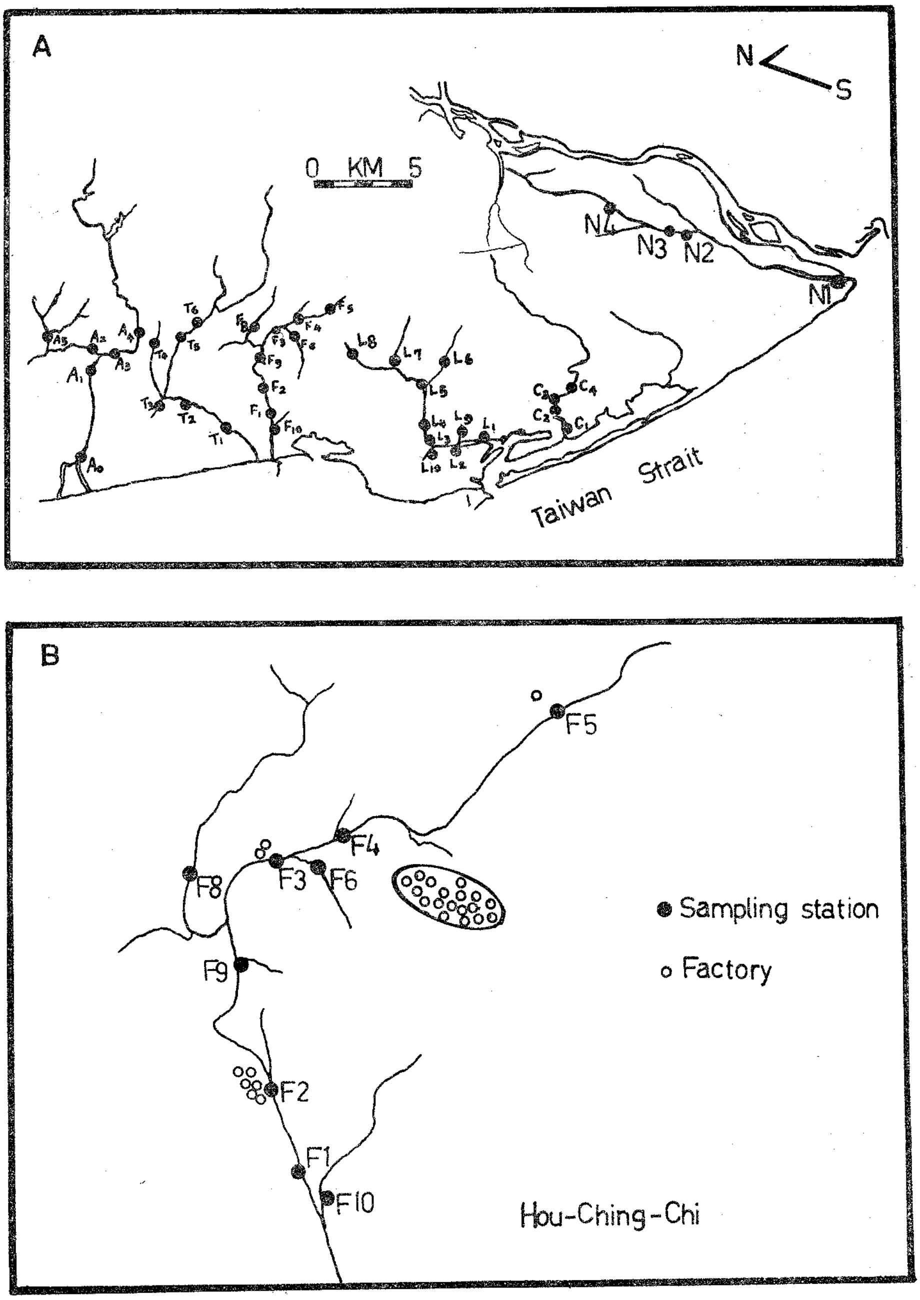

Fig. 1. A: The location of sampling stations of six rivers, namely Ar-Kong-Ten-Chi (station A_0–A_5), Chien-Cheng Ho (station C_1–C_4), Hou-Ching-Chi (station F_1–F_{10}), Jen-Ai-Ho (station L_1–L_{10}), Ning-Yuan-Chun (station N_1–N_4) and Ten-Paw-Chi (station T_1–T_6); B: the location of factories along Hou-Ching-Chi in the Kaohsiung area, Taiwan.

Sampling and preparation of waters

Waters from each of the aforementioned stations and factories were collected in 1976 and 1977. The samples were brought back to the laboratory of the Pilot Projebt of Pollution Control at Kaohsiung and were filtered immediately through Whatman No. 42 filter paper. Then the samples were sent back to the Institute of Botany, Academia Sinica, Taipei and stored in a cold room at 4°C. Before the waters were analyzed, they were refiltered with the filter paper.

Bioassay of waters

Two bioassay techniques described by Chou and Muller (1972) as well as Chou and Lin (1976) were adopted. Each water was bioassayed against 3 test plants, namely: rice (*Oryza sativa* Taichung 65), lettuce (*Lactuca sativa* var. Great Lakes 366), and rye grass (*Lolium multiflorum*). Distilled water served as a control. 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:

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

then, the negative value expresses the stimulation effect.

Physico-chemical analyses of waters

Each aforementioned sample was determined for its pH value by using Chemtrix type 40 pH meter, osmotic concentration by using Fiske G-66 osmometer, electrical conductivity by using YSI Model 31 conductivity bridge expressed by micromhos per cm at 25°C, and NH_4^+-N content by means of the Bear's technique (1960). The quantity of heavy metals, namely Cu^{2+} and Zn^{2+} was determined by using an atomic absorption spectrophotometer (Perkin-Elmer, Model 300). The data of total alkalinity were adopted by the courtesy of Professor T. C. Hung (Hung *et al.*, 1977).

Statistical analysis

For each river, the means of phytotoxicity obtained from the average of phytotoxicities of three test plants, namely rice, lettuce, and rye grass were used for the station index as the X axis; while the means of phytotoxicity obtained from each test species was used as the Y axis. The data of phytotoxicities in the X and Y axis were then analyzed by a linear regression analysis to see the level of significance of correlation coefficient between the test species and the sampling station that reflect the response of plant to the environmental locality.

Furthermore, to understand the correlation between the phytotoxicities present in each river and each physico-chemical property, a linear regression analysis was also performed by using the aforementioned data of station index as the X axis and each chemical data as the Y axis. Thus, the values of correlation coefficient tell us the significant level of correlation between phytotoxicity of the water and the chemical characteristics.

Results

Phytotoxic effect of waters on the radicle growth of three plants

The waters of Ar-Kong-Ten-Chi revealed significant phytotoxic effects on the radicle growth of lettuce, rice, and rye grass, being significant at 1% level (Fig. 2). The order of phytotoxicity present in this river station is A_4, A_5, A_2, A_1, A_3, and A_0, where A_0 exhibited the highest phytotoxicity and A_4 the least. However, only two station waters of this river, namely A_0 and A_3 were shown significantly phytotoxic on all test plants. It was obvious that lettuce

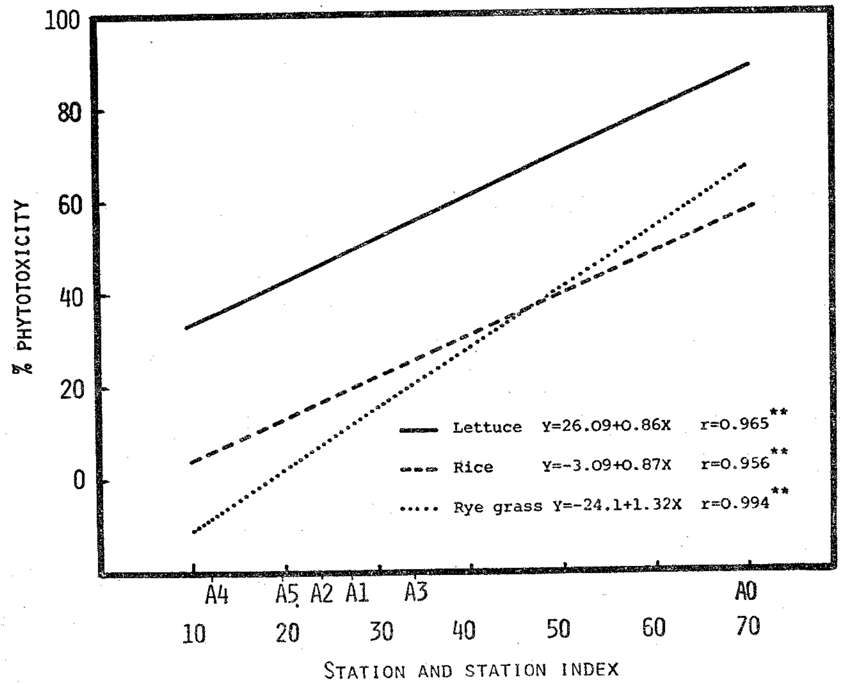

Fig. 2. The phytotoxic effect of Ar-Kong-Ten-Chi water on the radicle growth of three test plants, namely lettuce, rice, and rye grass. The % phytotoxicity was expressed as % inhibition of the waste waters against distilled water control. Asterisk, * and **, indicates the statstical significance at 5% and 1% level of confidence, respectively; and r indicates the correlation coefficient using a linear regression analysis. Station index was obtained from the average of phytotoxicities of three test plants mentioned.

was the most sensitive species in response to polluted waters, and rye grass was the least.

The bioassay results of Chien-Cheng-Ho are shown to be similar to that of Ar-Kong-Ten-Chi, and lettuce sharply responses to the polluted waters. The response of these three species to the polluted waters was signicantly different from each other (Fig. 3). Of the 4 sampling stations, C_1 exhibited the highest inhibition on all test species reaching about 100% phytotoxicity, C_2 was the next highest, and C_3 and C_4 were low showing about 30% inhibition (Fig. 3).

The phytotoxicity present in the water of Hou-Ching-Chi was much lower than that of the above mentioned two rivers. Only lettuce was shown to be significantly inhibited by the waters collected at F_8 and F_{10} stations (Fig. 4). Rice and rye grass were not inhibited by the water from this river. However, there is a vast area of agricultural land which borders this river where many crops have been severely jeopardized. These plants include rice, cabbage, turnip, and trapa, and the root, leaf, and fruit of these crops show that they were significantly suppressed (Fig. 5). It has been reported that the grain yield of rice along this river was reduced by at least 40%, and the numbers of tiller, panicle, and test weight (grain weight per 1,000 seeds) were greatly reduced by polluted water (Chou *et al.*, 1978).

In the waters of Jen-Ai-Ho, the phytotoxicity is exceedingly high, being 50% to 100% for lettuce, 40% to 70% for rye grass, and 15% to 70% for rice. The response of these species to the polluted waters is significantly different at 1% level of confidence (Fig. 6). Although Jen-Ai-Ho exhibits high phytotoxicity on plant growth, this river runs into the Kaohsiung harbor, thus the water is not detrimental to crops but it is harmful to sea organisms surrounding this area (Hung *et al.*, 1975).

With regard to Ning-Yuan-Chun's water, the phytotoxicity as revealed by the test species is generally very low and only lettuce was inhibited (Fig. 7). The regression coefficients are all below 5% level of significance which means these three species are not sensitive at the sampling location.

Finally, the phytotoxic effect of Ten-Paw-Chi's water on the plants is significantly different from each other (Fig. 8). The water at stations T_2 and T_1 show significant inhibition above 40%. Lettuce is again the most sensitive plant to the polluted water. The correlation coefficients are significantly different (Fig. 8).

As mentioned earlier, the rice productivity around the Hou-Ching-Chi has severely decreased. So our attention was directed to looking for the source of phytotoxicity in that river. We selected 27 factories along the Hou-Ching-Chi and the waste waters from them were bioassayed using the same techniques

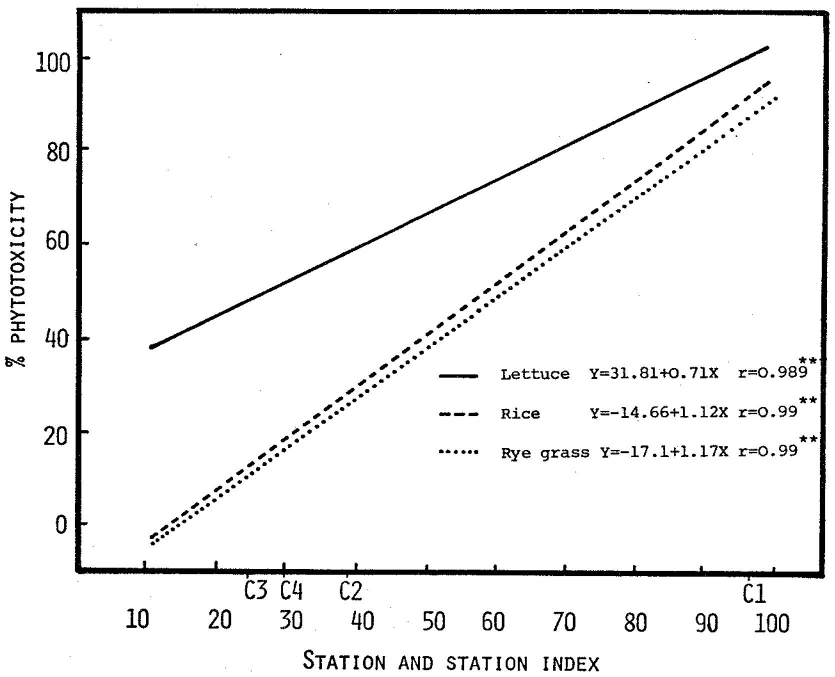

Fig. 3. The phytotoxic effect of Chien-Cheng-Ho water on the radicle growth of three test plants. The rests of description are the same as those shown in Fig. 2.

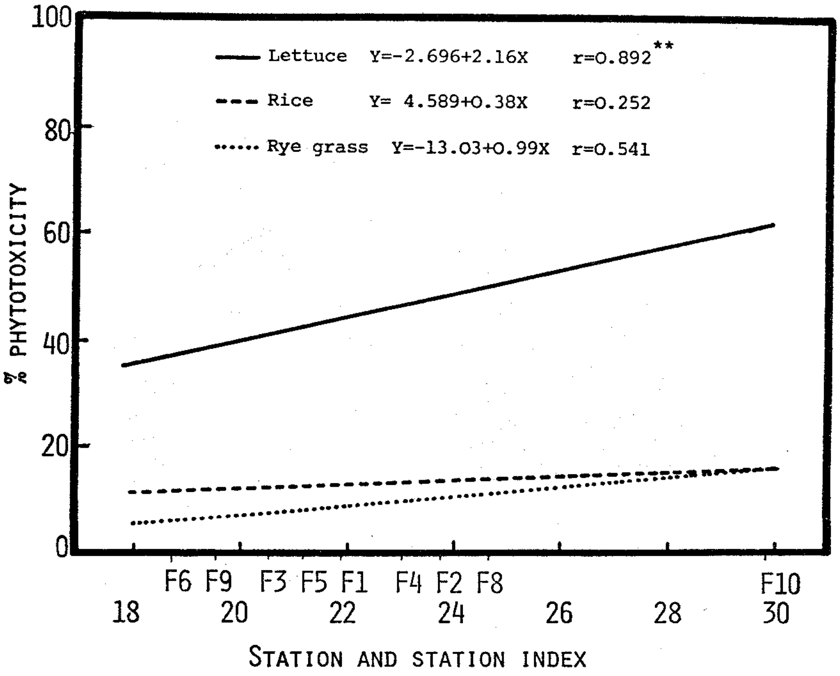

Fig. 4. The phytotoxic effect of Hou-Ching-Chi water on the radicle growth of three test plants. The rests of description are the same as those shown in Fig. 2.

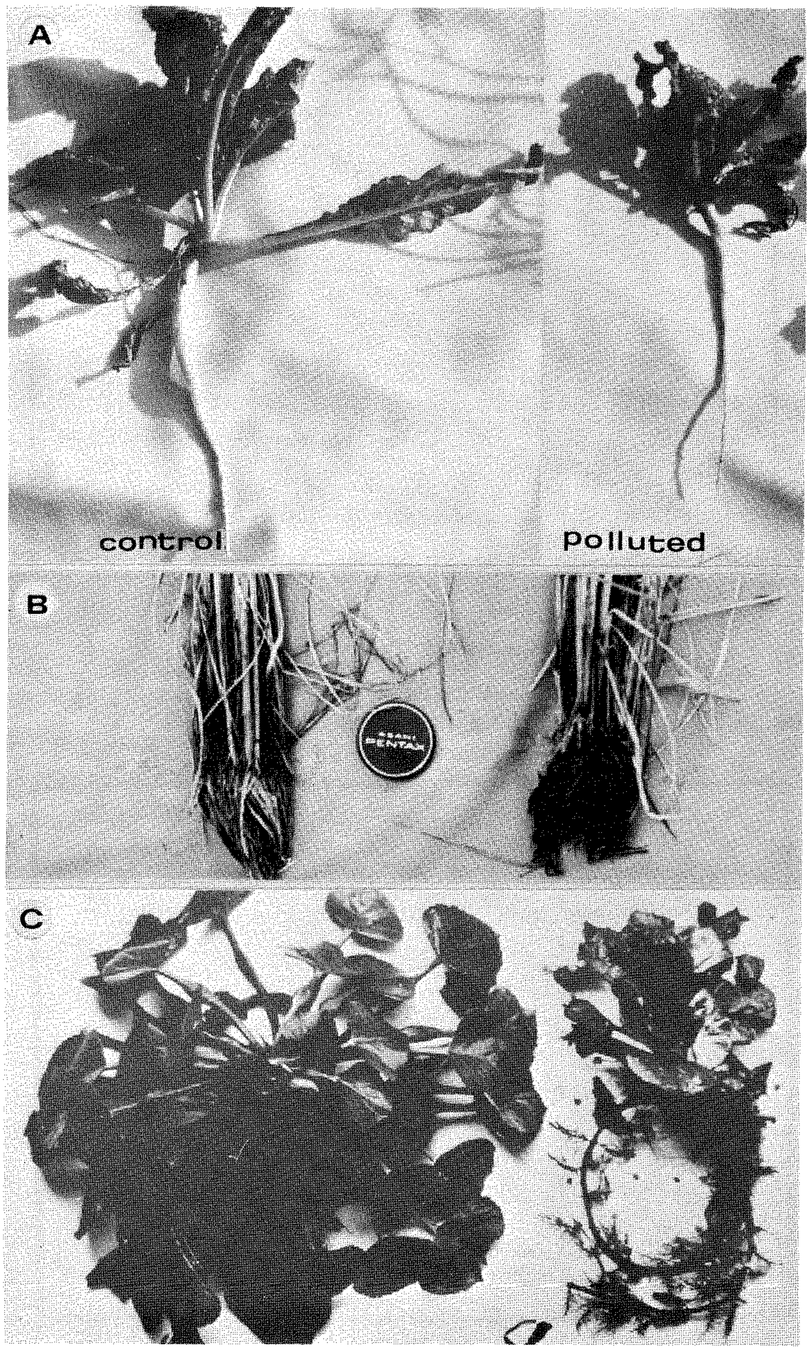

Fig. 5. The effects of polluted water on the growth of turnip (A), rice root (B), and trapa (C). All the left hand side photos are the plants growing in normal irrigation water without pollution as control and the right hand side ones are affected by polluted water.

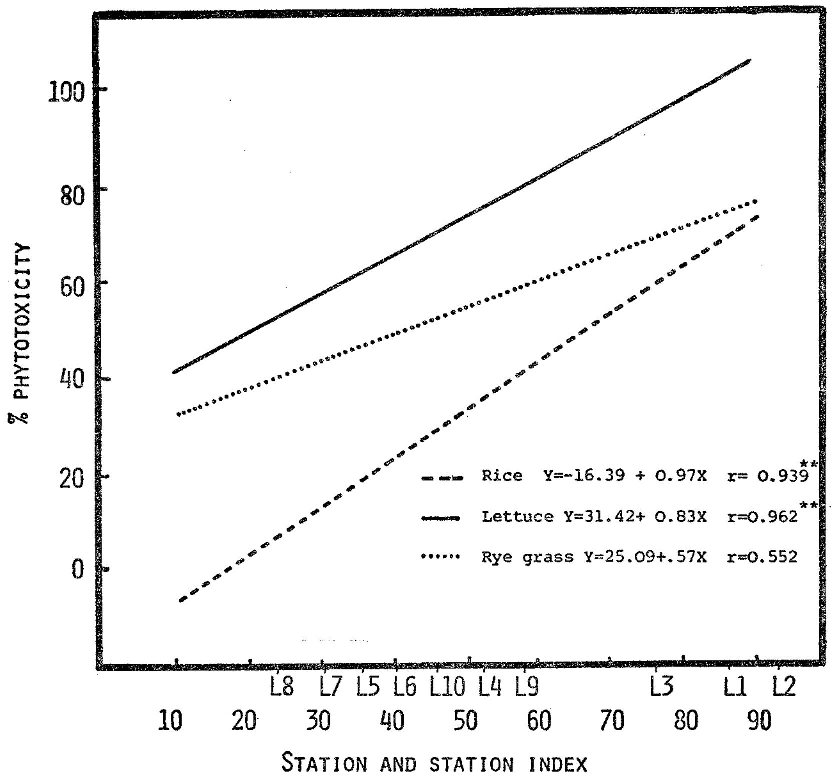

Fig. 6. The phytotoxic effect of Jen-Ai-Ho water on the radicle growth of three test plants. The rests of description are the same as those described in Fig. 2.

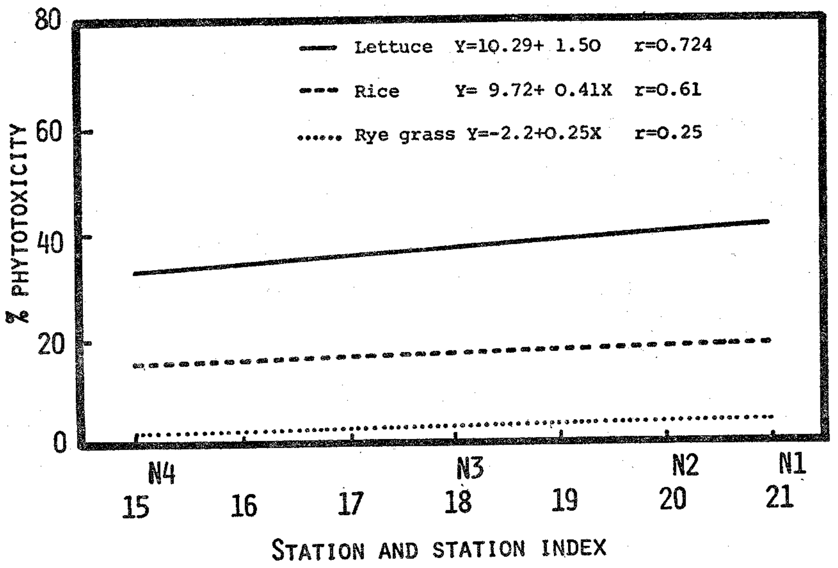

Fig. 7. The phytotoxic effect of Ning-Yuan-Chun water on the radicle growth of three test plants. The rests of description are the same as those shown in Fig. 2.

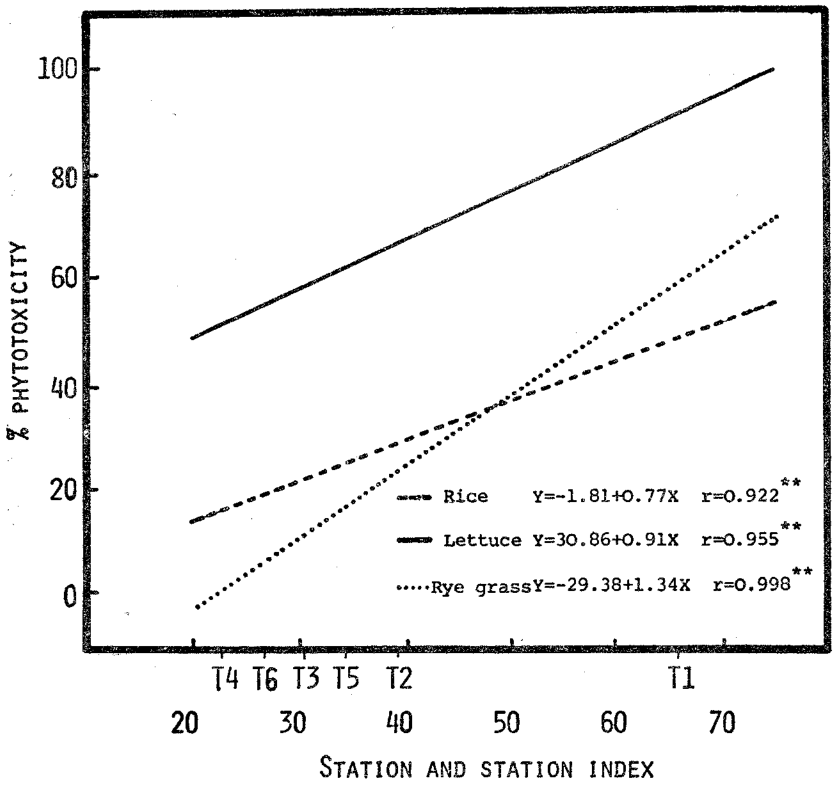

Fig. 8. The phytotoxic effect of Ten-Paw-Chi water on the radicle growth of three test plants. The rests of description are the same as those shown in Fig. 2.

and the same test species. The results of the bioassay are shown in Table 1. Around F_2 station, the waste waters coming from factories of Feng-Shi-Ta, Tung-I, and Hun-Kuo exhibited significant phytotoxicity on all test species, particularly the Feng-Shi-Ta showed nearly 100% inhibition on lettuce and rye grass, and 90% on rice. Around F_4 station, there are more than four factories whose waste waters revealed phytotoxicity higher than 65%. Among them, Ta-Nun, and Chung-Yu-Chu-Yun showed almost 100%, while Chung-Chien and Chung-Hua revealing phytotoxicity ranged from 65% to 91%. The waters from factories of Jeng-Ta, Ta-Cheng-Chang-Cheng, Tung-Chien, Kao-Nan, and Jen-Ko-Wei showed inhibition above 40%. In the area around F_3 and F_5 stations, only two factories, namely Swan-Lu and Ta-Ming-Battery exhibited significant phytotoxicity (Table 1). The findings of bioassay (Table 1) seem unlikely to be correlated to those of Fig. 4 in which the phytotoxicity is significantly low.

Physico-chemical natures of the polluted waters

It was thought that the phytotoxicities of the polluted waters were due to pH, osmotic concentration, electrical conductivty, NH_4^+-N content, total

Table 1. *Relative phytotoxicities of 27 industrial waste waters around Hou-Ching-Chi in Kaohsiung area*

Each phytotoxicity was obtained from at least 3 replications of 3 samplings.

Location	Factory	% Phytotoxicity			
		Lettuce	Rice	Rye grass	Means
F_2	Feng-Shi-Ta	97	90	99	95(1)
	Hun-Kuo	83	60	57	67(1)
	Tung-I	78	32	25	45(1)
	Tung-Yuan	52	21	4	26(2)
	Chou-Chi-Electronic	41	18	18	26(2)
	Shan-Yeh	20	18	0	13
F_3	Swan-Lu	85	73	88	82(1)
	Chung-Yu	47	20	7	25(2)
F_4	Chung-Yu-Chu-Yun	100	97	100	99(1)
	Ta-Nun	100	98	98	99(1)
	Chang-Chun	78	65	91	78(1)
	Chung-Chien	83	73	69	75(1)
	Jeng-Ta	60	18	52	43(1)
	Chung-Hua	62	21	29	37(2)
	Ta-Cheng-Chang-Cheng	49	32	11	31(2)
	Yung-Sing-Chemical	39	32	13	28(2)
	Tung-Chien	48	25	6	26(2)
	Jeng-Ko-Wei	42	31	1	25(2)
	Chien-Shun	39	9	20	23
	Li-Ching	39	16	14	23
	Far-East	34	9	23	22
	Kao-Nan	41	22	− 6	19
	Cheng-Chung	22	22	6	17
	Ta-Teh-Chang	23	17	0	13
	Fu-Lu	24	1	10	12
	Lien-Tai	14	− 6	− 4	1.3
F_5	Ta-Ming-Battery	94	43	33	57(1)

(1), (2): Statistical significance at 1% and 5% of confidence, respectively.

alkalinity, heavy metals, and phytotoxic substances. Except for the last one, detailed analyses of each water sample were made, and resuls were obtained. In Table 2, it shows that the pH value of all samples from 6 rivers ranged between pH 6.75 to 8.30, at which pH the radicle growth of the test plants was not affected. The osmotic concentration of waters varied with samples, being significantly different from each other. Some station samples exhibited exceedingly high osmotic concentration above 50 milliosmols which could cause plant injury (Chou and Young, 1974). These samples are A_0, A_3, C_1, C_2, L_1,

Table 2. *Some physio-chemical natures of waters in 6 rivers in Kaohsiung area*

The sampling stations are as follows: Ar-Kong-Ten-Chi (A_0 to A_5), Chien-Cheng-Ho (C_1 to C_4), Ning-Yuan-Chun (N_1 to N_4), Ten-Paw-Chi (T_1 to T_4), Hou-Ching-Chi (F_1 to F_{10}) and Jeng-Ai-Ho (L_1 to L_{10}).

Sampling station	pH	Osmotic conc. (mosmols)	Electric cond. (μ mhos/cm)	NH_4^+-N content (ppm)	Total alkalinity (ppm)	Cu^{2+} (ppm)	Zn^{2+} (ppm)
A_0	7.80	335.5	15,500	2.40	283	0.053	0.046
A_1	7.80	18.3	1,200	1.01	342	0.046	0.013
A_2	7.45	18.5	1,475	1.17	343	0.046	0.020
A_3	7.75	107.3	790	0.16	267	0.030	0.000
A_4	7.80	9.0	650	0.65	234	0.030	0.030
A_5	7.40	20.3	1,525	0.41	321	0.070	0.020
C_1	7.40	552.0	18,000	4.16	174	0.060	0.350
C_2	7.35	50.0	5,750	4.45	279	0.046	0.180
C_3	7.90	9.6	2,105	8.55	283	0.056	0.020
C_4	7.45	5.3	640	2.65	235	0.073	0.050
F_1	7.25	16.8	1,250	4.50	261	0.090	0.020
F_2	7.05	19.0	1,325	1.60	198	0.043	0.100
F_3	7.20	25.8	1,540	1.90	204	0.036	0.030
F_4	6.75	21.8	1,785	2.10	100	0.040	1.170
F_5	7.90	4.3	525	3.95	188	0.073	0.060
F_6	7.00	45.0	1,825	1.25	149	0.020	0.020
F_8	7.20	17.3	1,165	6.55	197	0.050	0.030
F_9	7.15	22.8	1,425	6.15	176	0.180	0.630
F_{10}	7.30	16.0	1,100	16.00	317	0.020	0.040
L_1	7.60	352.0	20,000	34.50	303	0.040	0.160
L_2	8.10	428.0	20,000	21.50	301	0.040	0.060
L_3	7.40	292.0	20,000	11.50	301	0.070	0.180
L_4	7.30	93.0	10,300	17.00	387	0.000	0.110
L_5	8.30	8.0	4,100	13.50	393	0.020	0.060
L_6	7.20	13.0	1,380	58.00	520	0.050	0.020
L_7	7.40	17.0	2,000	18.50	340	0.020	0.030
L_8	7.20	5.0	1,280	9.00	316	0.010	0.090
L_9	7.40	218.0	13,000	24.50	363	0.060	0.050
L_{10}	7.40	55.0	3,000	17.50	320	0.060	0.020
N_1	7.70	435.0	875	0.11	273	0.050	0.020
N_2	7.45	4.2	600	0.25	260	0.030	0.030
N_3	7.45	4.0	600	0.11	254	0.010	0.010
N_4	7.55	3.8	606	0.06	264	0.040	0.010
T_1	7.35	257.0	14,250	3.13	252	0.050	0.010
T_2	7.25	372.0	7,250	3.26	291	0.010	0.030
T_3	7.35	23.0	1,460	9.10	289	0.030	0.010
T_4	7.75	24.0	1,775	11.55	430	0.030	0.000
T_5	7.35	18.3	1,125	0.03	235	0.050	0.010
T_6	7.25	11.3	1,045	2.50	243	0.030	0.010

L_2, L_3, L_4, L_9, L_{10}, T_1 and T_2. Similarly, the data in electrical conductivity was correlated to osmotic concentration, and many samples showed their electrical conductivity above 750 μmhos/cm which is the minimum criteria for irrigation water for farms (recent Conference on Water Quality Control, 1978, Taipei). In the results of NH_4^+-N analyses of test waters, many exceeded 1.00 ppm which is also a minimum criteria for irrigation water suggested by that Conference. However, bioassay at this concentration of NH_4^+-N may not cause any phytotoxicity. Only a few samples, namely L_1 and L_6 were showed that their NH_4^+-N content was higher than 30 ppm, at which concentration rice growth may be retarded (Chou, 1978b). As far as total alkalinity is concerned, the data obtained from all test samples were insignificantly different, and gave no correlation to the phytotoxicity for each individual. The content of Cu^{2+} in all test samples was below 1 ppm, and the Zn^{2+} content in the samples was also very low (Table 2). So it is concluded that the heavy metals (Zn^{2+} and Cu^{2+}) are not the cause of phytotoxicity in these polluted waters.

The industrial waste waters from 27 factories were determined for their aforementioned physico-chemical characteristics. The results shown in Table 3 indicate that these characteristics vary with the samples, and are insignificantly correlated with phytotoxicity for each individual sample. For example, the pH values ranged from 4.6 to 11.9 in some waters analyzed, and so are beyond the safety range for irrigation water. The osmotic concentration of the tested waters were relatively low and only a few samples exceeded 45 milliosmols, i. e. Tung-I, Swan-Lu, Chung-Chien, and Far-East. As far as electrical conductivity is concerned, many samples exhibited higher than 750 μmhos/cm, which is the minimum criteria for irrigation water. Factories having such wastes include Feng-Shi-Ta, Tung-Yuan, Chou-Chi-Electronic, Swan-Lu, Chung-Yu, Ta-Nan, Chung-Hua, Jeng-Ta, Ta-Cheng-Chang-Cheng, Tung-Chien, Chien-Shun, Far East, Ta-Teh-Chang, and Ta-Ming-Battery. In the analysis of NH_4^+-N content, two factories, namely Chung-Yu-Chu-Yun and Chung-Chien showed the extremely high content of 390 ppm, at which concentration, plant growth would be retarded. The amount of total alkalinity in the test samples was irregular and was not significantly correlated with phytotoxicity. Finally, the quantity of heavy metals, such as Zn^{2+} and Cu^{2+} ions present in the waste waters from 27 factories, was lower than 1 ppm; exceptions were: Chien-Shun with 3.35 ppm for Cu^{2+}; and Feng-Shi-Ta, Chung-Chien and the Ta-Ming-Battery with 3.05, 1.50, and 3.42 ppm for Zn^{2+}, respectively (Table 3).

Correlation analysis between phytotoxicity and each physico-chemical nature

To elucidate the phytotoxic effects of each test samples, a linear regression

Table 3. *Some physico-chemical natures of 27 industrial waste waters around Hou-Ching-Chi in Kaohsiung area*

Location	Factory	pH	Osmotic con. (m osmols)	Electrical cond. (μ mhos/cm)	Concentration, (ppm)			
					NH_4^+-N	Total alkalinity(1)	Cu^{2+}	Zn^{2+}
F_2	Feng-Shi-Ta	7.8	17.0	1,180	1.90	290	0.05	3.05
	Hun-Kuo	4.6	2.0	630	0.10	110	2.62	0.05
	TungI	ND(2)	47.0	ND	1.00	1400	0.04	0.01
	Tung-Yuan	7.5	20.0	1,200	1.80	286	0.07	0.32
	Chou-Chi-Electronic	11.9	42.0	9,000	0.03	5630	0.04	0.11
	Shan-Yeh	ND	1.0	ND	0.03	180	0.05	0.09
F_3	Swan-Lu	4.6	47.0	1,530	28.00	536	0.02	0.14
	Chung-Yu	7.8	12.5	1,060	6.80	139	0.05	0.02
F_4	Chung-Yu-Chu-Yun	ND	35.5	ND	390.00	1300	0.02	0.00
	Ta-Nun	9.6	17.0	2,000	1.06	346	0.13	1.50
	Chang-Chun	ND	12.8	ND	ND	264	0.04	0.02
	Chung-Chien	—	170.0	—	390.00	1300	0.07	1.50
	Jeng-Ta	8.5	11.0	950	ND	227	0.05	0.09
	Chung-Hua	8.1	—	1,350	11.90	—	0.04	0.05
	Ta-Cheng-Chang-Cheng	6.9	14.0	990	7.40	361	0.01	0.01
	Yung-Sing-Chemical	ND	9.0	ND	1.10	329	0.00	0.05
	Tung-Chien	7.6	6.0	870	0.03	270	0.00	0.06
	Jeng-Ko-Wei	ND	5.0	442	0.20	297	0.03	0.00
	Chien-Shun	7.3	13.5	2,050	4.10	350	3.35	3.42
	Li-Ching	ND	1.5	ND	1.10	180	0.06	0.08
	Far-East	11.8	44.0	9,300	0.03	1060	0.07	0.08
	Kao-Nan	ND	19.5	ND	ND	312	0.03	0.02
	Cheng-Chung	ND	9.0	ND	1.10	329	0.00	0.05
	Ta-Teh-Chang	9.2	12.0	1,050	0.16	159	0.04	0.01
	Fu-Lu	ND	7.0	ND	0.03	190	0.01	0.09
	Lien-Tai	ND	11.0	ND	0.03	256	0.02	0.00
F_5	Ta-Ming-Battery	11.6	18.0	2,010	0.03	ND	0.28	0.63

(1) The data of total alkalinity were after Hung *et al.* (1977) with courtesy.

(2) ND: not detected.

analysis was made between phytotoxicity and each chemical characteristic obtained. The results of analyses are shown in Table 4, which indicates that the phytotoxicity in each river water is insignificantly correlated to its pH, total alkalinity, and content of Cu and Zn ions. However, the phytotoxicities in the waters of the Ar-Kong-Ten-Chi, Chien-Cheng-Ho, Jen-Ai-Ho, and Ten-Paw-Chi are correlated with electrical conductivity, furthermore, the phyto-

Table 4. *Statistical correlation between phytotoxicity and chemical natures of each water sample present in 6 rivers*

Data represent the correlation coefficient by using a linear regression analysis.

River	Phytotoxicity versus						
	Osmotic concentration	Electrical conductivity	NH_4^+-N	Total alkalinity	pH	Cu^{2+}	Zn^{2+}
Ar-Kong-Ten-Chi	0.986(1)	0.955(1)	0.834(2)	NS(3)	NS	NS	NS
Chien-Cheng-Ho	0.998(1)	0.985(1)	NS	0.879(1)	NS	NS	NS
Hou-Ching-Chi	NS	NS	0.80(2)	NS	NS	NS	NS
Jeng-Ai-Ho	0.960(1)	0.950(1)	NS	NS	NS	NS	NS
Ning-Yuan-Chun	NS	NS	NS	NS	NS	NS	NS
Teng-Paw-Chi	NS	0.94(1)	NS	NS	NS	NS	NS

(1), (2): Statistical significance at 1%, and 5% level, respectively.
(3): NS=Not significant.

toxicity of the first three is also correlated with osmotic concentration. Two river waters of Ar-Kong-Ten-Chi and Hou-Ching-Chi show their phytotoxicities being correlated with NH_4^+-N contents. It is concluded that the phytotoxicity found in the polluted waters are primarily due to the factors mentioned.

Discussion and Conclusions

In the course of our water pollution study in Taiwan, we have observed that many issues concerning the impact of water pollution on crop growth have been reported but only a few investigations have been made (Chen, 1975; Chou, 1978a; Chou *et al.*, 1978). In this study it becomes evident that among six rivers examined, the Chieng-Cheng-Ho and Jen-Ai-Ho exhibited the highest phytotoxic effect on lettuce, rice, and rye grass. However, two of these rivers run into the Kaohsiung harbor and Taiwan Strait so do not significantly affect the irrigation water used for crops but they may be detrimental to sea organisms. The other four river waters are used for irrigation on agricultural lands. Particularly, the vast area of paddy fields along the Hou-Ching-Chi is polluted by water coming from more than 33 factories (Chou *et al.*, 1978). Most of these factories release waters that are detrimental to various kinds of crops (Fig. 5). Among them lettuce was the most sensitive species to polluted waters, rice was second, and rye grass was least sensitive. Positive correlation was found between phytotoxicity and the chemical nature of the waters in some rivers (Table 4). The situation along the Hou-Ching-Chi seems contradictory for, although there are 27 factories along this river the phytotoxicity of its waters were low, as shown by this study. This may have been due to the dilution of pollutants by irrigation water. Nevertheless, some factories release polluted water in large amounts that eventually may become detrimental to soil fertility and influence the population of soil microorganisms. It was thought that trace amount of phytotoxic organics might be present in the polluted water. We have had difficulty in extracting phytotoxic organics from the polluted soil; however, several phenolic acids, namely *p*-hydroxybenzoic, *p*-coumaric, vanillic, and ferulic acids are present in the polluted soil and are likely present in higher concentrations than that in non-polluted soils (Chou *et al.*, 1977 unpublished data). We have attempted to find the responsible phytotoxins present in the polluted water and soils, but our results are not conclusive.

The study of water pollution on soil microorganisms should be deeply investigated because some pollutants may not directly suppress the growth of a crop but may stimulate the growth of microorganism. If this is the case, the nutrition imbalance and the formation of a dominant micro-organis may indirectly influence the growth of plants. Patrick *et al.* (1971) pointed out that plants may easily be susceptible to soil pathogens when the plant has been previously retarded by soil phytotoxins.

The dilution of polluted water by irrigation water may be helpful in decreasing the phytotoxicity of the water as far as its electrical conductivity, osmotic concentration, NH_4^+-N content, and heavy metal concentration are concerned. The young seedlings of rice or other crops usually are easily harmed by pollutants, so we suggest the use of non-polluted water for irrigation during the young seedling stage and the diluted polluted waters for the later stages. The control of polluted water running onto farm lands is of fundamental importance, otherwise, agricultural land will be greatly jeopardized and may never return to its original status if we do not prevent polluted water from running onto the fields.

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水污染對臺灣農作物生長的影響

II. 高雄地區六條溪河水及後勁溪沿岸二十七家工廠廢水的植物毒性作用

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臺灣區公害防治小組於一九七五年至一九七七年間進行高雄地區公害防治的研究。本研究室參與此計劃並研究此地區六條溪河水及後勁溪沿岸27家工廠廢水對植物生長影響。研究結果指出該地區的六條河川［前鎮河（Chien-Cheng-Ho）、仁愛河（Jen-Ai-Ho）、阿公店溪（Ar-Kong-Ten-Chi）、典寶溪（Ten-Paw-Chi）、後勁溪（Ho-Ching-Chi）及林園圳（Ning-Yuan-Chun）］及工廠廢水對萵苣生長之毒性程度最大，水稻次之，裸麥草最低。此六條河川之植物毒性程度以前鎮河及仁愛河最高，典寶溪及阿公店溪次之，後勁溪再次之而林園圳之河川水幾近無毒。田間的觀察研究指出，後勁溪地區的農作物中水稻及蔬菜普遍受污染水影響而致產量大減；水稻受污染水影響致使根系發育不良、倒伏、穗數分蘗數減少，致使產量減低；該地區之其他作物如菱角亦受危害。植物毒害原因與 pH 值及重金屬含量無相關關係，但與滲透濃度、電導度、及 NH_4^+-N 含量有相關關係。二十七家工廠廢水中，以大能（Ta-Nun）、中油儲運（Chung-Yu-Chu-Yun）、中纖（Chung-Chien）、晃國（Hou-Kuo）、豐士達（Feng-Shi-Ta）、眞達（Jeng-Ta）、及雙鹿（Swan-Lu）廠之廢水植物毒性達5%顯著水準；其中大能、中油儲運、中纖及雙鹿等廠之廢水所含之植物毒性高達75%至100%。其毒性原因雖與上述理化性質有正相關關係，此有待進一步之研究探討。