

鐵絲工廠酸洗廢水污染水田之復舊¹

林昭遠 謝慶芳 王錦堂²

摘 要

本試驗田位於距離一個鐵絲加工廠約有三十公尺之遙的較為低窪之地，工廠之酸洗廢水經由地下滲入田中，使該農田之水稻嚴重枯死，已經無法種植任何作物。經採取廢水、受污染土壤及受害稻株樣品分析結果，發現該農田水稻發育不良或枯死之主要原因為鐵絲工廠滲入之酸洗廢水使土壤之pH大幅下降、鹽分上升、並產生鐵及硫化氫之毒害，使水稻之根部和地上部之生長受到抑制或傷害。

每公頃撒施5公噸之碳酸石灰並每間隔15m、挖掘寬40cm，深50cm之小溝，按照0.5%之降坡埋設直徑4"之塑膠排水浪管實行排水之後，土壤之pH已經顯著回升，鹽分及可萃取性鐵和硫已經大幅下降，土壤條件已經大致恢復正常，適合於水稻之正常生產。

前 言

鐵絲工廠以鹽酸脫銹，所產生之酸洗廢水未經適當之處理，而排入田中；輕者往往因吸收過量之二價鐵離子(Fe^{++})而產生生理上之障礙⁽¹⁾，其症狀與一般排水較差之酸性土壤所引起之鐵之毒害症狀大致相同，主要是在較老之葉片產生細小之褐點或銹斑^(2,5,6,7,8,10,11,12)；重者則可能引起其他問題而使水稻發生枯萎現象。過去一些報當曾經指示，排水不良而引起硫化氫及鐵毒害之稻田，施用石灰並裝設暗管排水，可以很有效地使這些低產稻田之生產力急速地大幅增加^(2,4,9)。

本試驗之主要目的是要調查鐵絲脫銹工廠廢水使水稻枯死之原因；及埋設塑膠排水浪管並施用石灰，對那些遭受污染稻田之改良效果。

材料與方法

本試驗田位於臺中縣大里鄉，為一排水良好之砂頁岩沖積土，附近有一鐵絲工廠，其廢水經由土層滲透流入農田，使水稻發生嚴重之枯死現象(圖一)，已經無法種植任何農作物。由於農民之要求，於七十三年一期作水稻種植前進行復舊工作。首先採取廢水及受污染之稻田土壤及植物體樣品進行分析，以便瞭解使水稻枯死之污染因素。然後每隔15m挖寬40cm，深50cm之小溝，按照0.5%之降坡埋設直徑4"之塑膠排水浪管(圖二)，再按逢機完全區集三重複之設計法將埋設排水浪管之區域劃分為排水與未排水之小區，其間以深60cm之不透水塑膠布隔開，每小區面積為20平方公尺。

試區規劃完成後以灌溉水進行為期一個月之洗鹽工作，洗鹽過程中並按謝氏方法用醋酸鉛處理過之濾紙測定硫化氫之變化情形⁽⁴⁾，然後每公頃全面撒施5公噸之碳酸石灰，即刻開始

1. 臺中區農業改良場研究報告第 0091 號。

2. 分別為臺中區農業改良場助理、技正、助理研究員。



圖一 遭受鐵絲工廠酸洗廢水污染之稻田，水稻幾乎死光，僅留少數枯死之稻株在田間

Fig. 1 Almost barren paddy field with a few wilted rice plants due to contamination by the wastewater from the wire smelter



圖二 埋設塑膠排水浪管以便排洗土壤中過多之鹽分和有毒物質

Fig. 2 Constructing the corrugated drainage pipeline for removing off the excessive salts and toxic elements

整地。水稻品種採用臺農67號，於73年3月4日插秧，每橫5~6支，行株距為24cm×24cm，插秧後每星期排水一次。施肥量N-P₂O₅-K₂O為120-60-80 kg/ha，氮用尿素，磷用過磷酸鈣，鉀用氯化鉀。氮肥分別於基肥，一追、二追及穗肥各施25、20、30及25%。鉀肥於一追及二追各施40及60%。磷肥則全部當基肥使用。

土壤樣品於洗鹽前及水稻幼穗期分別採樣一次。採樣後立刻測定濕土之pH，並立即抽取新鮮土壤之飽和抽出液，測定其電導度及水溶性陰陽離子。土壤風乾後以蒸餾水調製水土飽和液測定其pH，並用其抽出液測定電導度。交換性陽離子之測定採用中性醋酸銨法。可萃取性微量元素以0.1NHCl抽出後用原子吸光儀測定。水稻幼穗期採取植物體樣品做全分析並調查稻株之農藝性狀。7月2日所有試區之水稻全部收割，調查其產量及產量構成因素。

結果與討論

從鐵絲工廠廢水之分析(表一)可以發現廢水之pH 1.8，顯然較一般正平之灌溉水為低，而鹽分93 mmhos/cm及鐵7500 ppm則較一般正常之灌溉水高出很多，其他錳、銅、鎳之含量也稍嫌過高。洗鹽前試區新鮮土壤及風乾土壤之分析(表二及三)也顯示遭受污染之土壤pH已經過低，而EC，鐵，及硫之含量均較一般正常之土壤高出很多。遭受污染稻田中枯死稻株地上部植物體之分析(表四)顯示稻株中鐵之含量7,250 ppm，已經遠超過可以引起鐵毒害之含量^(3,13)。另外在排水過程中也可以測到土壤中硫化氫含量逐漸降低之現象(圖三)，表示硫化氫毒害也是遭受污染稻田水稻發育不良之原因之一⁽⁴⁾。綜合上述資料，可以說遭受污染地區水稻發育不良或枯死之主要原因為土壤之pH過低而鹽分、鐵及硫之含量過高所致。

表一 鐵絲工廠酸洗廢水之化學分析

Table 1 Analysis of the wastewater from a wire smelter*

pH	EC	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni
	mmhos/cm (25°C)										
1.8	93	1.8	5	80	100	27	7,500	41	1.5	2.3	2.8

* Figures are the average values of three replications

表二 淋洗前所採取新鮮土壤之水土飽和體及其抽出液之化學分析

Table 2 Analysis of soil paste and saturation extract of the moist soils sampled before leaching*

Treatments	pH	EC	K	Na	Ca	Mg	Fe	Mn	Zn	Cu
		mmhos/cm (25°C)								
CK	3.0	16.2	12.5	80	25	172	1,460	67	13.5	0.25
Drained	2.8	16.2	10.0	112	55	121	1,780	54	14.0	0.15

* See table 1

表三 淋洗前所採取土壤樣品風乾後之化學分析

Table 3 Analysis of the air-dried soils sampled before leaching*

Treat- ments	Tex- ture	pH	EC mmhos/cm (25°C)	P			Exchangeable				Extractable				
				OM %	Bray 1	SO ₄	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni
CK	LS	2.7	7.0	3.15	9.2	1,939	35	60	240	172	1,494	165	160	10	34
Drained	LS	2.3	8.8	3.35	10.4	4,138	20	70	180	118	1,607	146	140	11	20

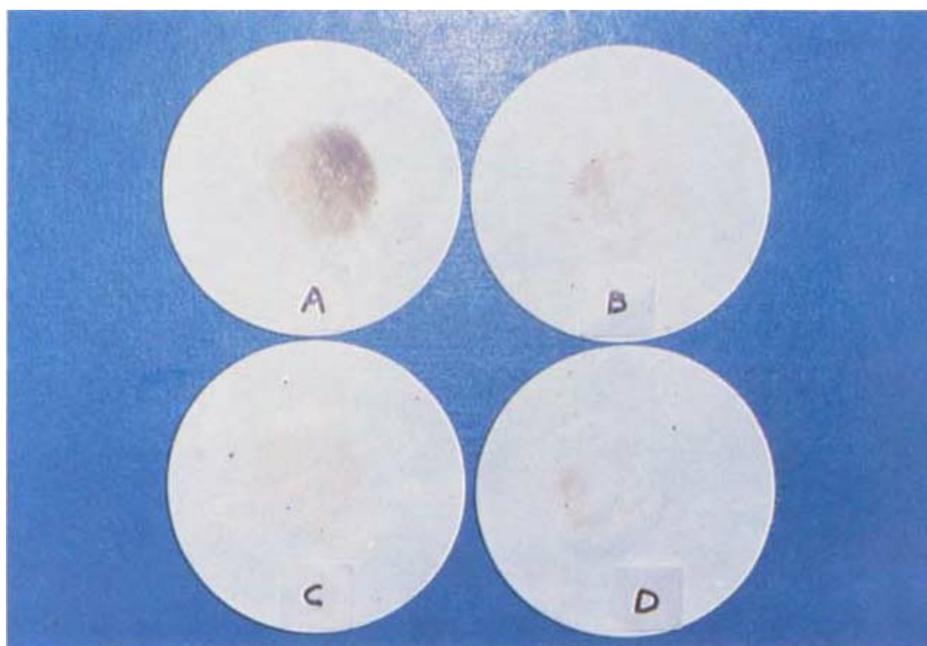
* See table 1

表四 改良前枯死水稻地上部之化學分析

Table 4 Analysis of the wilting rice plants (above ground parts) sampled before reclamation*

N	P	K	Na	Ca	Mg	S	Fe	Mn	Zn	Cu	Ni	
			%									
1.79	0.27	0.56	0.24	0.21	0.16	0.22	7,250	480	188	19	68	

* See table 1



圖三 受污染稻田於排洗過程中硫化氫由A逐漸降低至D
 Fig. 3 Decreasing in hydrogen sulphide contents from A to D in the contaminated paddy field during the course of drainage

從幼穗期新鮮土壤及風乾土壤之分析(表五及六)，可以發現排水區之pH已經極顯著地提高至4.3及4.1；鹽分則極顯著地降低至2.78及1.89 mmhos/cm；水溶性鐵極顯著地由380 ppm降至19.5 ppm，可萃取性鐵極顯著地由1,285 ppm降至1,020 ppm；交換性硫酸根由3,312 ppm降至2736 ppm；其他一些元素也均有顯著下降，表示埋設塑膠浪管排水之效果非常良好，已經使遭受鐵絲工廠廢水污染之農田完全恢復正常之生產力，而對照區之水稻發育仍然很差(圖四)，根部有明顯的受害現象(圖五)。

幼穗期水稻植物體之分析結果(表七及八)顯示對照區水稻地上部與地下部之鐵含量均極顯著地高於排水區，已經遠超過可以引起毒害之含量，根據吉田氏之報告⁽¹³⁾水稻分蘖期葉片之含鐵量超過300 ppm即會引起毒害，但本試驗排水區幼穗形成期水稻地上部和根部之含鐵量分別達到2,000及26,500 ppm，而稻株之生長與產量均已接近正常，且未發現毒害癥相。另外對照區之鎳與硫之含量也稍高於排水區，其他各元素處理間雖然也顯著之差異，但其含量均在正常範圍之內。由此可以推斷，對照區水稻老葉出現許多細小之褐色斑點是一種鐵之毒害現象(圖六)。



圖四 未加排洗之受污染稻田之稻株(下)及埋設塑膠浪管排洗稻田之稻株(上)生長情形
Fig. 4 Rice plants in the contaminated plots without drainage (bottom), and drained with corrugated drainage pipeline (top)



圖五 未加排洗之受污染稻田之稻株根部受害，植株矮化(左)，埋設塑膠浪管排洗之稻田稻株發育正常(右)

Fig. 5 Injured and retarded rice plants from the plot contaminated by the wastewater (left), and the normal rice plants from the plot drained through corrugated drainage pipeline (right)



圖六 遭受鐵毒害之水稻葉片出現許多細小之褐色斑點(左)，這些葉片常於陽光之下發生捲曲之現象(右)

Fig. 6 Rice plants suffered from iron toxicity showing the symptoms of many tiny brown spots on the leaves (left) that were often rolling under the sunshine (right)

表五 幼穗形成期所採取新鮮土壤水土飽和體及其抽出液之化學分析

Table 5 Analysis of soil paste and saturation extract of the moist soils sampled at panicle initiation stage

Treatments	pH	EC	K	Na	Ca	Mg	Fe	Mn	Zn
		mmhos/cm (25°C)							
CK	3.8 ^{b**}	7.40 ^{a**}	14.2 ^{a**}	42 ^{a*}	185	221	380.0 ^{a**}	39.3	1.5 ^{a**}
Drained	4.3 ^a	2.78 ^b	6.2 ^b	36 ^b	135	165	19.5 ^b	22.2	0.5 ^b

* and ** represent 5 and 1% significant levels by LSD test respectively

表六 幼穗形成期所採取土壤樣品風乾後之化學分析

Table 6 Analysis of the air-dried soils sampled at panicle initiation stage

Treatments	pH	EC	OM %	P	SO4	Exchangeable				Extractable				
		mmhos/cm (25°C)		Bray 1		K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni
CK	3.2 ^{b**}	3.85 ^{a**}	3.23 ^{a*}	19.2	3312 ^{a**}	48	65	1200 ^{a**}	249 ^{a**}	1285 ^{a**}	132	150 ^{a**}	9.7 ^{a*}	32
Drained	4.1 ^a	1.89 ^b	3.05 ^b	17.3	2736 ^b	48	58	800 ^b	179 ^b	1020 ^b	130	118 ^b	7.9 ^b	20

* and ** See table 5

表七 幼穗形成期水稻植物體之化學分析，ppm

Table 7 Mineral contents (ppm) of the rice plants at panicle initiation stage

Treatments	Fe		Mn		Zn		Cu		Ni	
	A	R	A	R	A	R	A	R	A	R
CK	9,300 ^{a**}	65,000 ^{a**}	515	265 ^{b**}	58 ^{b*}	93 ^{b**}	15	24 ^{b**}	52	702 ^{a**}
Drained	2,000 ^b	26,500 ^b	670	530 ^a	60 ^a	146 ^a	11	33 ^a	41	252 ^b

* and ** See table 5

A=above groundparts R=roots

表八 幼穗形成期水稻植物體之化學分析(%)

Table 8 Mineral content (%) of the rice plants at panicle initiation stage

Treatments	N		P		K		Na		Ca		Mg		S	
	A	R	A	R	A	R	A	R	A	R	A	R	A	R
CK	2.4 ^{b**}	1.20	0.32	0.24	1.4 ^{b**}	0.66	0.34	0.37	0.35	0.045	0.194	0.140	0.21 ^{a**}	0.28 ^{a**}
Drained	3.1 ^a	0.82	0.38	0.18	2.2 ^a	0.65	0.31	0.39	0.23	0.013	0.200	0.205	0.14 ^b	0.18 ^b

** See table 5

A=above groundparts R=roots

水稻生育期與成熟期之農藝性狀及產量構成因素調查結果(表九及十)顯示對照區水稻之地下部和地上部極明顯地受到抑制，根長、株高、分蘗數、每橫穗數、穗長、每穗粒數、千粒重、稔實率、稻穀產量都極顯著地低於排水區，沒有收割之經濟價值，而排水區之水稻無論地下部、地上部或稻穀產量都已經達到正常之程度。

綜合言之，本試驗田水稻發育不良或枯死之主要原因為該酸洗廢水使水田之pH大幅下降鹽分上升，並產生鐵及硫化氫之毒害，使水稻之根部和地上部之生長受到抑制或傷害。埋設4"塑膠浪管並施用石灰，可使土壤之pH回升，鹽分下降，並將還元性之鐵及硫化物氧化排洗使水田恢復正常之生產功能。

表九 插秧後 50 天稻株之農藝性狀

Table 9 Agronomic characters of rice plants at the 50th day after transplanting

Treatments	Root length (cm)	Root color	Tiller no.	Plant height (cm)
CK	14.0 ^{b**}	Reddish brown	6.3 ^{b**}	45.3 ^b
Drained	21.6 ^a	Yellowish brown	37.6 ^a	76.6 ^a

** See table 5

表十 成熟期水稻之農藝性狀及產量構成因素

Table 10 Agronomic characters and yield components of rice plants at maturing stage

Treatments	Plant height (cm)	Panicle No. per hill	Panicle length (cm)	No. of grain per panicle	1000 Grain weight (g)	Filled grain (%)	Grain yield (kg/ha)
CK	108.1 ^{b**}	7.9 ^{b**}	16.3 ^{b**}	70.0 ^{b**}	13.5 ^{b**}	6.5 ^{b**}	75 ^{b**}
Drained	118.5 ^a	21.3 ^a	18.4 ^a	80.5 ^a	24.0 ^a	63.7 ^a	4,500 ^a

** See table 5

參考文獻

1. 朱 鈞 郭華仁 蔡養正 1979 作物對金屬毒害之生理反應，科學農業 27(1-2)：3-7。
2. 謝慶芳 黃錦堂 林昭遠 1983 塑膠排水浪管改良稻田排水防止稻株鐵過多及鉀銅缺乏之研究 臺中區農業改良場研究彙報 7：90-98。
3. Chapman, Homer D. 1965. Diagnostic criteria for plants and soils. Chapter 15 Iron, pp. 203-212.
4. Hsieh, C. F., T. R. Tsai, H. C. Huang, and D. T. Chen. 1982. Poorly drained acid sulfate soils at Ta-An Township in the west coast of central Taiwan, Bulletin of Taichung District Agricultural Improvement Station, New Series No. 6:121-140.

5. Inada, K. 1966. studies on the bronzing disease of rice plant in Ceylon. I. Effect of field treatment on bronzing occurrence and changes in leaf respiration induced by the disease. *Trop. Agri.* 122:19–29.
6. Inada, K. 1966. Studies on the bronzing disease of rice plant in Ceylon. II> Cause of the occurrence of bronzing. *Trop. Agri.* 125:54–46.
7. Ota, Y. 1969. Studies on the occurrence of the physiological disease of rice called “Bronzing”. *Bull. Nat. Inst., Agri. Sci. (Japan) Ser. D*, 18:31–104.
8. Ponnampereuma, F. N., R. Bradfield, and M. Peech. 1955. Physiological disease of rice attributable to iron toxicity. *Nature* 175:265.
9. Ponnampereuma, F. N. 1958. Lime as a remedy for physiological disease of rice associated with excess iron. *Int. Rice Comm. Newslet.* 7(1):10–13.
10. Tanaka, A., R. Loe, and S. A. Navasero. 1966. Some mechanisms involved in the development of iron toxicity symptoms in the rice plant. *Soli Sci. Plant Nutr. (Tokyo)* 12:158–162.
11. Tanaka, A., R. P. Mulleriyawa, and T. Yasu. 1968. Possibility of hydrogen sulfide induced iron toxicity of rice plant. *Soli Sci. Plant Nutr.* 14:1–6.
12. Tanaka, A., and S. Yoshida. Nutritional disorders of the rice plant in Asia, IRRI, Los Banos, Lagnna, Philippines.
13. Yoshida, Shouichi, Douglas A. Forno, and James H. Cock. 1971. Laboratory manual for physiological studies of rice, IRRI, Los Banos, Lagnna, Philippines.

Restoration of the Productivity of Paddy Field Contaminated by the Acid Wastewater from the Wire Smelter¹

C. Y. Lin, C. F. Hsieh and C. T. Wang²

ABSTRACT

The experiment plot is located at a lower place with about 30 m distance from a wire smelter. The acid wastewater from the factory seeped through the soils to the plot to cause the serious wilting of rice plants, and the plot was unable to grow any more crops again without thorough land reclamation. The results of the analyses for the samples of wastewater, contaminated soils, and wilting plants suggested that the abnormal growth and wilting of rice plants in the plot was mainly caused by the abrupt decrease in pH, the abnormally high salinity and the toxicities of iron and hydrogen sulphide in the soils that rendered an inhibiting or harmful effects on the roots.

Broadcasting calcium carbonate at the rate of 5 tons per hectare, and constructing 4" corrugated drainage pipelines in accordance with the 0.5% decreasing slope, 50cm depth, and 15m interval, significantly raised the soil pH, and reduced the soil salinity, extractable iron and sulfur to the levels that were suitable for the normal growth of rice plants.

1. Contribution No. 0091 from Taichung DIAS.

2. Assistant, Associate Soil Specialist, and Assistant Soil Specialist of Taichung DAIS, respectively.