客土及施用穀殼對遭受銅素污染稻田之改良效果[1]

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摘　　要

本試驗是在中部地區一個遭受銅電鍍廢水污染而完全無法種植作物之水田舉行。試驗結果摘要如下：

1. 土壤中濃度過高之銅離子，主要抑制水稻根部之生長，因而影響營養之吸收及整個水稻植株之正常發育。在極端情況下，根部完全停止生長，並變得肥厚，根尖發生分叉現象。
2. 每公頃使用1000公升硫酸無法有效地洗掉超量之銅離子，但每公頃使用20噸之穀殼即可顯著地抑制銅離子之吸收，使水稻在較高銅離子濃度之土壤中仍可獲得正常生長。
3. 客土5至10 cm水稻即已大致獲得正常之生長，而客土15 cm則全部獲得正常之生長，但稻株之生長及產量構成因素在三種不同客土深度間並沒有顯著之差異。
4. 過多之銅離子主要集中在水稻之根部，稻穀之含銅量並未見增加，因而在銅素污染稻田生產之稻谷仍適合於一般消費之用。

前　　言

本省中部地區常有農田遭受廢水污染之問題，有些農田遭受污染之後農作物即長期無法生長，較輕者，作物發育亦參差不齊，產量銳減。一般農民遇此情形均束手無策，有些則想盡方法要設法恢復其生產力，可是多數均徒勞無功，所以如何採取經濟有效之方法，指導這些農民恢復其農田生產力，乃刻不容緩之問題，另一方面農作物遭受污染之後，對人體健康是否有不良影響，也極需調查研究，以維護國民之健康。

本試驗希望比較各種客土深度及硫酸淋洗並施穀殼對遭受銅離子毒害稻田之改良效果，並借水稻植物體之分析以瞭解銅素在植物體內之分佈情況，及其對人體健康可能之影響。

材料及方法

本試驗在臺中縣烏日鄉一處遭受銅毒害之農田舉行，該農田曾經種植玉米及水稻均無法正常生長(圖一及二)。試驗之作物爲水稻臺農67號，詳細處理如下：

(1)對照。

(2)每公頃以1000公升之濃硫酸(稀釋100倍)灌洗，三天後再以一般灌漑水淋洗三次，然後施下苦土石灰4000公斤，穀殼20公噸，經過四天穀殼沉下去後即開始翻耕整地。

(3)客土5公分。

(4)客土10公分。

(5)客土15公分。

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[1] 臺中區農業改良場研究報告第0081號。

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試驗設計採用逢機完全區集排列，重複四次，每小區10平方公尺，水稻臺農67號於3月5日插秧，每叢種植6支，行株距爲24 cm×21 cm，施肥量氮、磷酐、氧化鉀分別爲105、120及72公斤/公頃，按照標準方法使用，土壤樣品於田區規劃後進行處理並種植水稻45天後從各小區採取做全分析，並調查其根部受害症狀；於7月1日調查株高、每叢穗數，並採取植物體分爲根、老葉、劍葉、穀粒及全株五部分做全分析，以便瞭解銅在植物體之分佈情形。分析氮、磷、鉀、鈣、鎂之植物體使用硫酸與過氧化氫消化後分別用分光光譜儀，火焰光度計及原子吸光儀測定；分析銅、錳、鋅、鐵之植物體則用硝酸與過氯酸消化後用原子吸光儀測定。全部水稻於7月3日收割調查其產量及產量構成因素。

結果與討論

水稻種植後45天時從各處理採取土壤樣品分析結果(表一)，對照區0~5 cm，5~10 cm，10~15 cm等三層土壤之含銅量相當高，分別爲239、235及189 ppm，水稻植株明顯地矮化、分蘖少(圖四)，根部之生長受到阻礙，既短且少而肥厚，尖端產生分叉，嚴重者完全停止生長(圖三)，顯然是因爲表層土壤中之含銅量過高而對水稻根部發生毒害作用，因而抑制了根部之生長及營養之吸收。銅對作物根部之毒害作用，過去學者已經有類似之報告[(3)]。

表一、水稻種植後 45 天時之土壤之理化性質

Table 1. Chemical analysis for the soils sampled on the 45 days after transplanting

Treatments[++] and depth of Soil (cm)	pH	OM (%)	Brayl P (ppm)	Exchangeable Na (ppm)	K	Ca	Mg	Extractable Fe (ppm)	Mn	Zn	Cu
1. 0-5	5.8	1.46	27	58	37	321	100	133	17	10	239[a**]
5-10	6.3	1.39	33	55	36	266	85	129	12	10	235[c**]
10-15	6.3	0.93	26	47	37	213	75	115	9	8	180
2. 0-5	6.4	1.61	29	61	32	354	148	132	8	9	230[a]
5-10	6.4	1.49	33	55	30	248	137	133	10	11	239[c]
10-15	6.3	0.79	29	48	31	207	93	119	8	9	186
3. 0-5	6.8	0.73	7	60	37	526	123	118	78	5	76[b]
5-10	6.6	1.30	25	56	27	386	87	121	57	8	237[c]
10-15	6.8	1.39	35	47	32	400	87	120	19	9	237
4. 0-5	7.4	0.47	14	68	38	620	117	113	87	4	35[b]
5-10	7.4	0.68	11	72	46	568	94	119	69	6	132[d]
10-15	7.1	0.87	24	54	34	496	95	121	41	9	188
5. 0-5	7.7	0.55	7	63	41	643	115	111	84	4	20[b]
5-10	7.5	0.68	8	55	27	591	100	106	76	5	66[e]
10-15	7.1	0.93	22	55	31	475	104	111	41	9	148

** Significantly different at 1% level by Duncan's multiple range test (means are compared separately by layers.)

++ See table 2 for description of treatments.

硫酸淋洗並施石灰及穀殼區，各層土壤之含銅量均與對照區大致相同，表土0~5 cm、5~10 cm、10~15 cm等三層分別為230、239及186 ppm (表一)，表示每公頃使用1000公升硫酸無法洗掉多餘之銅離子，但水稻之發育正常，其原因似乎是穀殼產生之有機物可以吸附土壤中銅離子，因而減少水稻對銅離子之吸收(表十)，使其在較高銅離子濃度之情況下，仍可正常生長(表十一)。

客土5 cm區0~5 cm層之含銅量極顯著地降為76 ppm，但5~10 cm及10~15 cm層仍相當高，同為237 ppm (表一)，不過水稻生長已經大致正常(表十一)，此一結果表示，銅對水稻之毒害作用，以0~5 cm層之部分作用最大，5 cm以下之土層含銅量雖然很高，對水稻之影響已經大幅減少。客土10 cm及15 cm區之0~5 cm及5~10 cm層之含銅量都極顯著地降低至35、20、132和66 ppm，而10~15 cm層之含銅量仍相當高，分別為188及148 ppm，水稻生長情形似乎較客土5 cm者為佳，但其差異未達到顯著水準。

從成熟期水稻植物體之分析，發現對照區水稻全株和劍葉之氮和磷含量都顯著或極顯著地高於硫酸淋洗區和客土區，而鉀之含量則只有對照區和硫酸淋洗區之根部極顯著地低於客土區，其餘差異都不顯著，此一現象可能是因為對照區之稻株和根部生長受阻，不但根部無法正常吸收養分，而且吸收之後也無法充分利用於生長所致(表二、三、四)

表二、試驗區成熟期水稻植物體之含氮量(%)

Table 2. Nitrogen content in rice plant at maturing stage (%)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	0.53	0.67[a**]	0.90	1.26[a*]	0.76
2. S. acid/lime/r. hull[1)]	0.52	0.46[b]	0.75	0.99[b]	0.73
3. Soil introduction, 5 cm	0.52	0.46[b]	0.81	1.02[b]	0.77
4. Soil introduction, 10 cm	0.49	0.43[b]	0.67	0.97[b]	0.75
5. Soil introduction, 15 cm	0.50	0.43[b]	0.84	1.00[b]	0.77

* and ** Respectively significantly different at 5 and 1% level by Duncan's multiple range test.

1) S. acid/lime/r. hull means leached with sulfuric acid and then treated with lime and rice hull.

表三、試驗區成熟期水稻植物體之含磷量(%)

Table 3. Phosphorus content in rice plant at maturing stage (%)

Treatmenst	Roost	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	0.11	0.13[a*]	0.19	0.24[a**]	0.27
2. S. acid/lime/r. hull	0.11	0.10[ab]	0.16	0.16[b]	0.25
3. Soil introduction, 5 cm	0.14	0.09[b]	0.13	0.15[b]	0.31
4. Soil introduction, 10 cm	0.09	0.08[b]	0.13	0.14[b]	0.27
5. Soil introduction, 15 cm	0.11	0.07[b]	0.14	0.13[b]	0.30

* and ** Same as table 2.

表四、試驗區成熟期水稻植物體之含鉀量(%)
Table 4. Potassium content in rice plant at maturing stage (%)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	0.43[b**]	1.69	1.87	1.69	0.47
2. S. acid/lime/r. hull	0.33[b]	1.71	1.74	1.55	0.55
3. Soil introduction, 5 cm	0.72[a]	1.65	1.69	1.49	0.58
4. Soil introduction, 10 cm	0.72[a]	1.74	1.65	1.50	0.59
5. Soil introduction, 15 cm	0.87[a]	1.72	1.70	1.56	0.63

** Same as table 2.

表五、試驗區成熟期水稻植物體之含鈣量(%)
Table 5. Calcium content in rice plant at maturing stage (%)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	0.033	0.210	0.653	0.788	0.031
2. S. acid/lime/r. hull	0.042	0.187	0.508	0.748	0.031
3. Soil introduction, 5 cm	0.034	0.195	0.580	0.761	0.034
4. Soil introduction, 10 cm	0.043	0.208	0.580	0.799	0.035
5. Soil introduction, 15 cm	0.042	0.197	0.572	0.819	0.037

表六、試驗區成熟期水稻植物體之含鎂量(%)
Table 6. Magnesium content in rice plant at maturing stage (%)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	0.11	0.10[a*]	0.08[c**]	0.06[ab**]	0.14
2. S. acid/lime/r. hull	0.11	0.07[b]	0.07[c]	0.01[c]	0.17
3. Soil introduction, 5 cm	0.13	0.10[a]	0.09[bc]	0.03[bc]	0.18
4. Soil introduction, 10 cm	0.14	0.12[a]	0.14[ab]	0.07[a]	0.19
5. Soil introduction, 15 cm	0.14	0.12[a]	0.16[a]	0.08[a]	0.22

* and ** Same as table 2.

表七、試驗區成熟期水稻植物體之含鐵量(ppm)
Table 7. Iron content in rice plant at maturing stage (ppm)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	1247	229	286a*	224a**	108
2. S. acid/lime/r. hull	990	208	199b	151b	106
3. Soil introduction, 5 cm	1350	235	248a	199ab	111
4. Soil introduction, 10 cm	1202	225	263a	238a	104
5. Soil introduction, 15 cm	1043	194	274a	210a	114

* and ** Same as table 2.

表八、試驗區成熟期水稻植物體之含錳量(ppm)
Table 8. Manganese content in rice plant at maturing stage (ppm)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	83b**	200b*	208b**	184b*	40b**
2. S. acid/lime/r. hull	45b	66b	70c	63c	30b
3. Soil introduction, 5c m	229a	508a	783a	680a	98a
4. Soil introduction, 10 cm	283a	560a	755a	745a	126a
5. Soil introduction, 15 cm	313a	473a	725a	713a	118a

* and ** Same as table 2.

表九、試驗區成熟期水稻植物體之含鋅量(ppm)
Table 9. Zinc content in rice plant at maturing stage (ppm)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	94	55a*	51	28	33
2. S. acid/lime/r. hull	74	42b	34	21	32
3. Soil introduction, 5 cm	97	73a	43	25	35
4. Soil introduction, 10 cm	101	71a	48	37	39
5. Soil introduction, 15 cm	92	70a	50	30	37

* Same as table 2

表十、試驗區成熟期水稻植物體之含銅量(ppm)
Table 10. Copper content in rice plant at maturing stage (ppm)

Treatments	Roots	Whole plant	Lower leaf	Broad leaf (sword leaf)	Rice grain
1. Control	760[a*]	14[a**]	10	11[a*]	16
2. S. acid/lime/r. hull	294[b]	8[b]	7	9[b]	18
3. Soil introduction, 5 cm	119[b]	6[b]	8	9[b]	16
4. Soil introduction, 10 cm	97[b]	8[b]	9	10[ab]	16
5. Soil introduction, 15 cm	81[b]	8[b]	9	9[b]	18

* and ** Same as table 2.

從成熟期水稻植物體之分析(表五、六、七、八、九)，發現植物體中鈣之含量處理間並無顯著之差異，但硫酸淋洗區水稻植物體許多部位之鎂、鐵、錳、鋅都顯著或極顯著地低於其他處理，由於本處理土壤中上述各元素之含量都與其他各處理大致相同，所以植物體中這些元素之降低，似乎是受到穀殼所產生有機質之吸附作用之影響。同樣地，硫酸淋洗區土壤中銅之含量雖與對照區大致相同，但植物體中之銅含量卻顯著或極顯著地低於對照區(表十)，水稻之發育也正常，顯然也是受到穀殼所產生有機質之吸附作用之影響。此一發現與過去一些學者所報告：有機質可以固定土壤中之銅及其他金屬元素，使其有效性降低[4,6,7,10,12]，其結合並有一定之結構[1,2,5]和穩定常數[8,9,10]等相符合。另外所有客土區之植物體含銅量均顯著地低於對照區(表十)，表示遭受銅污染之土壤只要客土5~15 cm即可有效地防治銅之毒害作用。

表十一、試驗區水稻之生長、產量構成因素及產量
Table 11. Growth, yield components and yield of rice

Treatments	Plant height (cm)	No. of panicle per hill	No. of grain per panicle	Filled grain (%)	1000 grain weight (g)	Grain yield (kg/10m^2)	Index (%)	Straw yield (kg/10m^2)	Grain/ straw ratio
1.Control	81.3[b**]	9.5[b*]*	45.4[**]	81.2	26.3	2.51[b**]	100	2.67[b**]	0.94
2.S. acid/lime/r. hull	100.6[a]	14.9[a]	79.3[a]	86.9	26.3	4.98[a]	198.4	5.03[a]	0.99
3.Soil introduction, 5cm	96.8[a]	13.7[a]	69.7[a]	88.5	26.5	4.70[a]	187.3	4.47[a]	1.05
4.Soil introduction, 10cm	97.4[a]	15.0[a]	66.4[a]	87.4	26.3	4.75[a]	189.2	4.73[a]	1.00
5.Soil introduction, 15cm	100.8[a]	16.7[a]	72.3[a]	85.9	26.5	5.04[a]	200.8	5.22[a]	0.97

* Same as table 2.

成熟期調查水稻生長、產量構成因素及產量(表十一)，發現對照區之水稻株高、每欉穗數，每穗粒數、稻穀與稻草產量均極顯著地低於其他各處理，表示銅之毒害使水稻之生長、分蘗與結實受到嚴重之抑制，但施用穀殼或客土卻可使其生長與產量恢復正常。由於銅素是集中在水稻根部爲害而未大量移動到穀粒(表十)，所以遭受銅污染農田所種植之水稻除了產量較低之外，其稻穀仍可供一般消費之用。

圖一、在銅污染之土壤栽培之玉米，根部生長嚴重地受阻、欉生而有許多分叉。
Fig. 1. Seriously retarded, branched, and clustered corn roots in the copper contaminated soils before land reclamation.

圖二、在銅污染之土壤栽培之玉米，發生嚴重之缺株，植株生長也嚴重地受阻。
Fig. 2. Retarded and dwarfed corn plants and missing hills in the copper contaminated soils before land reclamation.

圖三、遭受銅毒害之水稻根部生長嚴重受阻或完全停止生長，根端產生分叉現象(CK)，客土 15 公分或使用硫酸/石灰/穀殼之處理根部正常。

Fig. 3. Seriously or completely retarded roots with branched tips on the rice plants from the copper contaminated plot (CK), and the normal root systems on the plants from the 15 cm soil introduction or s. acid/lime/rice hull soil treatment.

圖四、遭受銅毒害之水稻分蘗數非常少，植株矮小(CK)，但客土 5 至 10 公分者植株生長大致正常。

Fig. 4. Very few tiller number and dwarfed rice plants in the copper contaminated plot (CK), and almost normal plants in the 5 to 10 cm soil introduction plots.

結　　論

土壤中銅離子對水稻之毒害作用，主要是抑制其根部之生長，因而影響其他各部分植物體之正常發育。每公頃使用1000公升之濃硫酸尚無法達到洗除過量銅離子之作用，但使用穀殼20噸卻有抑制水稻吸收銅離子之效果，因而使水稻能夠在較高銅離子濃度之土壤中仍可正常生長。客土之效果最好，一般言之，客土5至10公分，水稻即可大致獲得正常之生長，客土15公分則可全部獲得正常之生長。過多之銅離子主要集中在水稻根部，而穀粒之含銅量並未見增加，因而遭受銅素污染農田所生產之稻谷仍適合於一般消費之用。

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Introduction of Soil or Treatment of Rice Hull for the Restoration of the Productivity of the Copper Contaminated Soil[1]

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ABSTRACT

This experiment was carried out in a paddy field in central Taiwan where the soil was rendered unproductive due to the contamination by copper in the wastewater from the brass spare parts manufacturing factory. The results are summarized as follow:

1. Excessively higher concentration of copper in the soils mainly retarded the growth of rice roots, and hence affected the nutrient uptake and the normal growth of the whole rice plants. In the extreme cases, the rice roots were completly inhibited in growth and thickened with branched root tip.
2. Soil treatment of sulfuric acid at the rate of 1000 ℓ/ha was ineffective for leaching out the excessive copper in the soils, however, rice hull at the rate of 20 tons/ha significanthy retarded the uptake of copper by the rice plants, and the rice plants were able to grow normally under the higher concentration of copper in the soils.
3. The rice plants looked growing almost normal in the 5 and 10 cm top layers and completely normal in the 15 cm top layer of the normal soils introduced to the copper contaminated paddy field, however, the growth and yield components of rice plants among the three different depths of soil introduction were not significantly different.
4. The pollutant, copper, was mainly concentrated in the rice roots, and the copper content in the rice grain was not increased, therefore, the rice grain from the copper contaminated plots was still suitable for human consumption.

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