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STUDIES ON TUNG-SHAN PADDY SOILS

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Studies on Tung-shan Paddy Soils

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For years, farmers of Tung-shan Hsiang, Yi-lan Hsien have experienced much difficulty in growing satisfactory rice crops on their farms. Local people call those unproductive lands "Chin-sng Tsan" (瀞酸田) which means "cool acid farm". The yield of paddy rice grain from the normal healthy farm is about 3,000 catties, while that of the affected is usually less than 1,000 catties per hectare and in extreme cases, no harvest at all. Shibuya and Torii(15) claimed good results from potash fertilization on such soils in the area, suggesting an antagonistic action between potash and iron. They concluded that the excessive concentration of soluble iron in soil water combined with potassium salts in the soil, under certain conditions, forming a kind of double salt such as $K_2SO_4 \cdot FeSO_4 \cdot nH_2O$ and decreased potash availability. Since the soil they studied for the experiment was only confined to a very limited area in Tai-ho (太和) village, and the crop injury has never occurred to any noticeable degree in that village during the past years, more detailed studies covering the whole Tung-shan area are required to establish the real detrimental factors to crop growth. The purpose of this contribution was primarily to ascertain the actual cause of crop failure and try to find a clue to reclamation program in the area.

Field Survey

Field surveys were made from time to time to ascertain the exact acreage and distribution of the farms affected and also to determine what environmental conditions were responsible for the injury to, and poor growth of, plants in Tung-shan area. A map was prepared, with the cooperation of local people, showing the distribution of the farms affected together with their severity of crop damage. Since considerable farm acreage was undoubtedly spared serious crop damage because of highly favorable weather conditions during the first crop in 1955, farmers' statements on their past experience were to a great deal taken for reference in the course of mapping. The survey revealed the following:

1. The total acreage of the farms affected is estimated at some 200 hectares, more than 90 per cent of which are distributed in the four villages, San-chi (三奇), Pu-chen (補城), Hsiang-ho (香和), and Ta-hsing (大興). In general, the severity was more pronounced in Hsiang-ho village.

Table 1. Distribution of "Chin-sng Tsan" in Tung-shan Hsiang (1st crop, 1955)

Location	Affected Acreage (ha)
Ta-na-me (打那美)	3
Yuan-shan (員山)	5

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Sun-ang (順安)	3
Ta-hsing (大興，舊名阿兼城)	37
Hsiang-ho (香和，舊名香員宅)	54
San-chi (三奇，舊名奇武荖)	62
Tung-kua-shan (冬瓜山)	2
Chin-chu-ri-chen (珍珠里簡)	2
Pu-chen (補城)	57
Total	225

2. The annual precipitation averages 2558 mm. in this area, nearly half of which falls during the period from September to December. Droughts are rare, and the danger of injury to crop is rather from excessive rainfall than from insufficient moisture supply. In fact, during years of low rainfall these soils may yield well. Relatively scanty rainfall in early summer may render transplanting of the second crop difficult. Consequently farmers in this area usually inter-plant the second crop seedlings shortly after the first weeding in the first crop.

3. Soils of this area are of recent slate alluvium and have loamy texture ranging from gravelly sandy loam to silt loam. Farms with gravelly substratum underneath, in general, suffer less damage to the rice crop even when the drainage is exceedingly poor as a result of high water table.

4. The occurrence of the injury generally does not appear very pronounced until about a month after transplanting in the first crop. In severe cases, plants may die at this stage. Examination of the roots reveals no evidence of insect damage. The roots of the injured plants, generally smaller in volume, have fewer branching rootlets than healthy plants of corresponding age. The symptoms displayed are characteristic of Helminthosporiose, more commonly known as "Sesame leaf spot disease". Although the same symptoms have been reported to occur in the degraded paddy soils in Japan, profile examination and subsequent laboratory tests pointed out no indications of such degradation in this area.

5. The injury occurs more rapidly and extensively in wet years than in dry years, and in the first crop than in the second crop. Quite a few farmers unanimously stated that scud showers after a spell of fine hot weather can bring about serious crop damage on those farms affected and that the very contrary occurs in the case of normal paddy farms.

6. "Honrai" varieties are more sensitive to the injury than native varieties. The majority of farmers grow those native varieties such as "A-lung" (亜倫) and "Hu-loo-tung"(胡蘆敦); the latter is said to be more resistant.

7. Very frequently there were healthy rice plants growing next to the injured.

8. The use of commercial fertilizers containing nitrogen, phosphorus, and potassium did not seem to influence the crop damage significantly.

9. The application of straw ash has been proved to be effective in some measure in controling the crop injury, although the effect is not always consistent.

10. There is a divergence of opinion on the effect of farm manures to such soils, some farmers saying it is favorable and others saying it is injurious.

11. High water table and poor drainage conditions prevail in the area. The surface of the ground water showed the peculiar iridescent film characteristic of chalybeate waters when they come in contact with air. Such waters contain ferrous carbonate and generally manganous carbonate held in solution by carbon dioxide. The ferrous iron at the surface is oxidized and precipitated as a thin film. Frequently one can encounter iron rust sediments in the ditch water somewhere around the farms affected.

12. Draining water immediately after the first weeding has been proved favorable and is the accepted practice both on the affected and normal farms.

13. Dry land cultivation, usually half a year to one year of vegetables or sweet potatoes prior to the first crop is by far the most effective and common practice in preventing serious crop damage. However, this favorable effect holds only untill the next year and never longer.

14. Microrelief undoubtedly has an important bearing on the crop injury in the area. The affected spots are in general, more or less depressed as compared to the adjacent healthy spots. Bringing soil into the farm from other high lands to raise the soil level is said to be the most consistent reclamation practice for the farms affected although this immediately involves much difficulty both in expense and for labor facilities. The writers encountered a good illustration in Hsiang-ho village of such a practice by which farmers had eliminated their long standing farm troubles.

15. The acreage of "Ching-sng Tsan" has been decreasing year by year in the past decade, although very gradually.

It appeared from the survey that there was sufficient evidence leading one to suspect that either or both of the following causes might be responsible for the crop injury; 1) Toxicity of soluble iron or manganese developed under poor drainage conditions which prevail in the area. Common occurrence of iron rust sediments in ditch water and the good effect of dry land cultivation ahead of the rice crop may provide the ground for this inference. 2) Potash deficiency as suggested by the experimental data of the Japanese period. The favorable effect of straw ash is another bit of evidence.

With these facts in mind, the following experiments were carried out.

Soil Analysis

Samples were collected from the top soil of the farms affected and the adjoining healthy spots in paddy fields in Tung-shan Hsiang in April, 1955, about two months after transplanting when the crop damage was quite apparent. Soils were air dried, thoroughly mixed, passed a 1 mm. sieve, and subjected to laboratory analysis for pH (Glass electrode), organic matter(18), total nitrogen(2), available phosphorus(14), and potassium(3), specific conductance (soil water ratio of 1:1), total and water soluble iron and manganese. Total Fe and Mn were determined by digesting 2.5 gm. of sample with 10 cc. of HCl (Sp. gr. 1.1) for 1 hour on a hot plate, then iron was determined by the ordinary gravimetric method and manganese by the colorimetric method using potassium

Table 2. Soil Data (Top Soil)

Crop Symptoms	Location	Soil No.	pH	Org. M. %	Total N %	Avail. P p. p. m.	Avail. K p. p. m.	Conductance Micromhos	Total Fe_2O_3 %	Total MnO %	Soluble Fe p. p. m.	Soluble Mn p. p. m.	Permeability cm/hr.	Note
Severe	Ta-hsing	10	7.00	3.89	0.24	25	10	570	10.74	0.046	18	29	2.5	
	Hsiang-ho	26	6.60	2.81	0.16	20	33	470	8.57	0.083	21	12	3.1	
		37	6.36	2.65	0.15	21	95	390	8.52	0.093	14	16	2.6	
		42	6.20	3.26	0.21	13	51	390	11.28	0·184	14	35	2.6	
Moderate	San-chi	2	7.40	3.40	0.23	14	95	480	9.88	0.113	30	20	2.1	Rotation*
		3	5.70	5.13	0.32	22	144	710	11.94	0.093	150	24	1.6	
		4	5.70	2.46	0.21	38	14	610	11.48	0.135	86	67	2.3	High ground water table
		6	7.40	2.69	0.17	26	13	650	10.24	0.057	20	4	2.5	
		7	7.41	2.60	0.18	24	18	760	11.54	0.092	18	13	2.3	Rotation*
		8	7.60	2.72	0.18	26	16	500	10.64	0.103	16	18	3.6	
	Ta-hsing	11	6.32	3.68	0.22	27	26	400	10.91	0.100	20	20	2.6	Rotation*
	Nan-hsing	16	5.80	3.00	0.17	30	70	520	11.36	0.072	22	31	1.9	
	Pu-chen	17	6.60	2.67	0.15	29	23	420	11.34	0.059	15	12	1.8	
	Hsiang-ho	24	5.85	3.80	0.22	22	90	840	11.00	0.101	33	23	3.1	
		35	7.00	2.95	0.17	15	85	570	8.51	0.100	18	13	2.6	
		39	5.82	3.72	0.23	11	80	480	9.72	0.135	20	12	2.2	
Slight	San-chi	1	5.30	3.37	0.21	12	48	570	9.85	0.068	94	11	1.4	
		5	7.00	2.94	0.18	26	13	690	10.10	0.012	67	16	1.6	
	Pu-chen	19	5.62	3.75	0.25	20	18	540	11.38	0.092	30	34	1.7	Rotation*
		20	5.72	3.97	0.24	24	54	420	11.01	0.067	32	21	1.7	Rotation*
	Hsiang-ho	38	6.25	3.94	0.21	13	45	430	7.55	0.063	16	4	3.8	Rotation*
None	Ta-hsing	12	5.50	3.47	0.20	35	36	350	10.58	0.075	34	6	2.4	
		14	5.25	3.03	0.19	24	124	460	9.48	0.052	84	29	2.0	
	Pu-chen	18	5.50	3.31	0.14	27	26	600	11.21	0.071	15	14	1.5	Rotation*
		40	5.46	3.82	0.25	18	60	500	10.12	0.064	37	27	1.7	
		21	5.25	3.98	0.24	29	95	610	10.60	0.067	56	22	1.1	Flood area in wet season
	Nan-hsing	23	5.58	2.81	0.16	24	106	530	11.00	0.068	34	27	2.6	Rotation*
	Hsiang-ho	36	6.05	3.03	0.15	12	85	370	8.27	0.071	24	7	2.4	
		41	5.50	2.28	0.13	20	60	340	6.51	0.095	23	1	2.4	Gravelly Sandy Loam

* Rotation: Sweet potato (or vegetables)—Rice.

Table 3. Soil Data (Profiles from seriously affected farms)

Profiel	Depth (cm)	Soil No.	pH	Org. M. %	Total N %	Avail. P p. p. m.	Avail. K p. p. m.	Conductance Micro-mhos	Total Fe_2O_3 %	Total MnO %	Soluble Fe p. p. m.	Soluble Mn p. p. m.	Permeability cm/hr	Note*
I	0–15	26	6.60	2.81	0.16	20	33	470	8.57	0.083	21	12	3.1	Slit loam. Olive gray mottled with yellow and reddish brown, comparatively loose. Plant roots sparsely distributed.
	15–25	27	7.60	1.52	0.08	15	45	370	9.36	0.093	15	2	1.6	Silt loam. Grey, compact, more or less stratified.
	25–33	28	7.65	0.98	0.06	10	57	220	8.37	0.103	18	1	1.3	Silt loam. Yellowish grey, structureless.
	33–39	29	7.90	0.37	0.06	9	45	310	9.69	0.079	14	1	3.2	Sandy loam. Yellowish grey. Water table (35 cm).
	39–56	30	7.45	0.63	0.07	15	95	450	9.32	0.051	14	2	0.9	Silt loam. Grey.
	56–62	31	7.70	0.45	0.07	19	85	280	7.96	0.079	17	1	2.6	Silt loam. Dark grey.
	62–	32	7.70	0.57	0.06	20	90	330	9.24	0.121	20	trace	1.2	Silt loam. Sticky. Grey.
II	0–10	42	6.20	3.26	0.21	13	51	390	11.28	0.184	14	35	2.6	Silt loam. Yellowish brown with grey mottlings.
	10–19	43	5.50	2.21	0.14				12.27	0.135	20	6	1.2	Silt loam. Ashy grey with yellowish brown blotches.
	19–35	45	6.70	1.02	0.06				11.10	0.138	20	4	1.3	Silt loam. Grey. Slightly blotched.
	35–41	46	7.40	0.88	0.07				11.26	0.102	22	1	0.9	Silt loam. Grey with faint brown shade.
	41–	47	7.70	0.34	0.05				9.48	0.180	18	1	1.3	Silt loam. Dark grey. Water table (50 cm).

* Due to wet conditions no structural development was evident.

periodate. Soluble iron and manganese were determined tentatively as follows; 50 gm. of soil was placed in an Erlenmeyer flask with 250 cc. of distilled water, the flasks were stoppered tightly creating anaerobic conditions. The flasks were shaken thoroughly once a day and the solution was drawn out at the end of 4 days, filtered and analyzed for iron and manganese. The method here adopted is somewhat similar to that of Robinson(13). Determinations were made colorimetrically, after perchloric, nitric, and sulfuric acids digestion using thiocyanate method for Fe and periodate method for Mn(12). Results are expressed on the basis of air dry soil. In addition to chemical analyses, permeability measurements were made on the disturbed soils following the procedure as described by Fireman(4). The soil analysis data are collectively presented in tables 2 and 3.

The data showed that soils in Tung-shan area, regardless of whether from affected or normal farms, are in general, fairly high in organic matter, nitrogen, available phosphorus, low in available potassium, and did not show excessive accumulation of soluble salts. A few high analyses of available K in the affected farms must be due to the recent top dressing of straw ash, since farmers used to apply straw ash in the early stage of crop injury in order to prevent further serious crop damage. Some troubles involved in arriving at a method of soluble-iron determination have been encountered. The iron is in solution in the ferrous form and may be largely colloidal. In any attempt at filtration much of the iron is oxidized to the ferric state and removed from solution. The soil analyses failed to show any consistent trends or relationships when the data were grouped according to crop symptom classes, nevertheless, there seems to be an indication that severe crop damage is most likely to occur on soils of higher pH values ranging from slightly acid to slightly alkaline; and reducing conditions might be more pronounced in these soils since high soil pH is usually associated with low Eh in soil as shown by many investgators(11, 17). The development of a low oxidation-reduction potential is largely dependent upon the decomposition of active organic matter in the soil and the breakdown of the organic matter was undoubtedly influencing the solubility of iron and manganese, especially the latter one as revealed in profile data (table 3). The quantity of iron and manganese made soluble was not in proportion to the total quantity present in the soil and this agrees with the results obtained by Robinson(13).

Water Analysis

Along with soil examination, general analyses were made on four water samples, three of which were collected from Tung-shan Hsiang and one from university farm in Taipei for comparison. All of these waters were used for irrigation of rice crop. Waters were sampled in February, 1955. The analyses are given in table 4. Comparatively high content of sesquioxides in ditch and well waters certainly have a bearing upon iron rust sedimentation.

Table 4. Water Analyses (p. p. m.)

	Location	pH	Total Solids	SiO_2	Fe_2O_3+ Al_2O_3	K_2O	Na_2O	CaO	MgO	SO_4^{--}	HCO_3^-
Ditch Water	Tung-shan	7.8	193	12	7	14	2	40	5	7	102
Well Water	Tung-shan	8.1	166	11	10	10	10	44	8	8	90
U-Lau-Kung River Water	Tung-shan	7.7	89	7	2	11	1	83	4	3	30
Liu-Kung-Sung Irrigation Water	Taipei	7.5	72	9	3	8	3	36	3	2	35

Plant Analysis

Plant samples were obtained shortly after the collection of soil samples from paddy fields showing the characteristic damage in varying degrees. In order to avoid soil contamination, samples were rinsed with tap water prior to drying. After drying at 80°C. in an air oven, the materials were ground in a small Wiley mill, redried and stored in air-tight containers. Aliquot samples were weighed out and analysed for N, P, K, Fe, and Mn. Total nitrogen was determined by the Gunning method(1). Samples were digested by the HNO_3-$HClO_4$-H_2SO_4 procedure and then P, Fe, and Mn determined by the methods outlined by Piper(12). Potassium was determined by the combination of cobaltinitrite and perchlorate methods after dry ashing. The analyses are given in tables 5, 6, 7, 8, and 9.

Table 5. Nitrogen Content of Plants (% N)

Symptoms \ Plant Sample No.	I	II	III	IV	V	Mean
Severe	3.19	2.60	3.28	3.07	2.93	3.01
Moderate	3.09	2.59	3.39	2.71	2.99	2.95
Slight	2.38	2.14	2.11			2.21
None	2.23	2.17	2.70			2.36

F=8.28** F0.05=3.49 F0.01=5.95

Table 6. Phosphorus Content of Plants (% P_2O_5)

Symptoms \ Plant Sample No.	I	II	III	IV	V	Mean
Severe	0.856	0.686	0.856	0.962	0.750	0.822
Moderate	0.919	0.891	0.856	0.657	0.912	0.847
Slight	0.898	0.799	0.637			0.778
None	0.870	0.820	0.650			0.780

F=2.94 F0.05=8.74 F0.01=27.05

Table 7. Potassium Content of Plants (% K_2O)

Symptoms \ Plant Sample No.	I	II	III	IV	V	Mean
Severe	1.904	1.047	1.428	1.701	0.810	1.387
Moderate	2.603	2.955	1.533	1.300	1.263	1.931
Slight	2.093	1.282	1.205			1.527
None	1.396	1.229	1.350			1.325

$F=1.07$ $\quad F_{.05}=3.49$ $\quad F_{.01}=5.95$

Table 8. Iron Content of Plants (% Fe)

Symptoms \ Plant Sample No.	I	II	III	IV	V	Mean	Difference		
Severe	0.180	0.244	0.161	0.206	0.260	0.210			
Moderate	0.074	0.161	0.172	0.200	0.174	0.156	0.054*		
Slight	0.116	0.067	0.065			0.083	0.127**	0.073*	
None	0.050	0.072	0.051			0.058	0.152**	0.098**	0.025

L. S. D. between mean of:

"Severe" and "Moderate"................................0.054(5%) 0.075(1%)

"Severe" and "Slight"
"Severe" and "None"
"Moderate" and "Slight"
"Moderate" and "None" } ....0.062(5%) 0.087(1%)

"Slight" and "None' ....0.069(5%) 0.097(1%)

Table 9. Manganese Content of Plants (% Mn)

Symptoms \ Plant Sample No.	I	II	III	IV	V	Mean	Difference		
Severe	0.113	0.117	0.072	0.085	0.170	0.112			
Moderate	0.100	0.080	0.070	0.050	0.070	0.074	0.038*		
Slight	0.061	0.067	0.049			0.059	0.053*	0.015	
None	0.056	0.045	0.068			0.056	0.056**	0.018	0.003

L. S. D. between mean of:

"Severe" and "Moderate"................................0.034(5%) 0.048(1%)

"Severe" and "Slight"
"Severe" and "None"
"Moderate" and "Slight"
"Moderate" and "None" } ....0.040(5%) 0.056(1%)

"Slight" and "None".......................................0.036(5%) 0.051(1%)

Lower percentages of nutrient elements in the normal healthy plants might have resulted from the dilution of these elements through increased yield rather than from reduction of total amount of the elements absorbed, yet the difference in Fe and Mn contents between the affected and healthy plants was quite significant. Injured plants have an average of more than three times as much iron and about twice as much manganese as normal plants. A very significant correlation was found between the crop symptoms and iron content of plants as shown in table 8.

Although the preceding soil analyses failed to offer a sure clue to iron and manganese excess in the affected soils, it is quite possible, considering the field observations together with the plant analyses, that soluble iron, and possibly manganese too, might exist in the affected spots to such an extent as would be toxic to plant growth since under reducing conditions such as develop in poorly drained soils ferric iron and manganese salts are frequently reduced and brought into solution by the action of certain reducing agents, particularly hydrogen sulfide. Iron and manganese have similar chemistry as regards oxidation, reduction, and their accompanying solubilities. In toxic concentrations Fe^{++} and Mn^{++} may cause very slow plant growth and poor root development as often indicated in the literature. It has been confirmed by one of the writers(9) through sand culture experiments with rice plants that, at the same concentratons, the toxicity of Fe^{++} is greater than that of Mn^{++} and the older the seedling the more tolerant it is to iron excess. High concentration of soluble iron was observed to cause very stunted growth of rice plants, the symptom identical to that observed in the affected field, and verified the suspicion that it was caused by iron toxicity.

Greenhouse Experiments

Experiment 1: In order to test the effect of some soil treatments on the growth of rice plants and their iron and manganese uptake, the first experiment was conducted from May 10 to June 29 in 1954. Top soil of an affected paddy farm in Hsiang-ho village was used for the experiment. 16 kg. of wet soil, equivalent to 12 kg. of dry weight, with strong musty odor was added to each pot and subjected to the following treatments:

No.	Treatments
1.	Control.
2.	Water supply controled. Occasionally kept the surface dry and cracked improving soil aeration.
3.	Soil was air-dried prior to flooding.
4.	Soil was drained ahead of planting.
5.	0.5 gm. K_2O applied as K_2SO_4.
6.	1.0 gm. K_2O. applied as K_2SO_4.
7.	2.0 gm. K_2O. applied as K_2SO_4.
8.	10 p. p. m. Cu applied as $CuSO_4 \cdot 5H_2O$.
9.	20 p. p. m. Cu. applied as $CuSO_4 \cdot 5H_2O$.
10.	50 p. p. m. Cu. applied as $CuSO_4 \cdot 5H_2O$.
11.	50 p. p. m. applied as $MnSO_4 \cdot 4H_2O$.

All of the treatments, in duplicate, received 0.6 gm. of N and P_2O_5 supplied as sulfate of ammonium and superphosphate of lime respectively. Six rice seedlings of the native variety were transplanted to each pot and the soil was kept water-logged during the course of experiment except in treatments 2 and 4. Plants were sampled before earing and analyzed for iron and manganese. Soil Eh of the upper 10 cm. was measured at the termination of the experiment. The results are given in table 10.

Table 10. Yield and Plant Composition as Affected by Various Soil Treatments

Treatment No.	Yield of Dry Matter* (g)	Fe %	Mn %	Soil Eh (m. v.)	Plant Growth
1	10.5	0.058	0.160	20	Fair
2	20.6	0.050	0.113	100	Good
3	8.6	0.063	0.100	10	Poor
4	14.7	0.044	0.112	150	Fair
5	12.2	0.044	0.114	30	do
6	11.2	0.040	0.101	30	do
7	12.1	0.045	0.085	20	do
8	11.8	0.046	0.085	40	do
9	13.9	0.055	0.068	30	do
10	25.7	0.055	0.060	20	Good
11	7.0	0.040	0.168	20	Poor

* L. S. D. between treatments (5%) = 4.2 (1%) = 5.9

Significant yield increase was obtained from water control practice and copper treatment, as shown in the table. It is of interest that the yield was as great with a heavy dose of copper as with soil aeration improvement although additions of copper sulfate did not increase soil Eh. It has been shown by many investigators (1, 5, 19, 20, 21) that copper has a beneficial effect on soils high in organic mater, soluble iron, and manganese. Although the mechanism involved is not well established most of the investigators attributed the response to the catalitic action of copper in oxidation-reduction reactions. The favorable effects of this element on muck soils, according to Joffe(7), are due in some measure to the precipitation of crenic and aprocrenic acids, and also some other toxic substances in the soil. Judging from the exceedingly low Eh values regardless of various soil treatments, the effect of copper in water-logged soil might be largely internal rather than due to reactions external to plant roots. In other words, copper may influence the immobilization of toxic substances in the plant such as Fe^{++} and Mn^{++}. Favorable response to water control practices such as in treatments 2 and 4 is in agreement with farmers' experience. Response to potash fertilization was not significant, however, plant analyses gave some evidence of antagonism between potassium and iron. Iron uptake was also reduced by application of manganese sulfate.

Contrary to expectation, air drying of soil ahead of flooding (treatment 3) showed depressive effect on plant growth. The most probable explanation is that air drying renders the organic matter more decomposable, which in turn may create more reduced soil conditions after flooding. Large amounts of ferrous iron thus produced might be responsible for the poor plant growth. In fact, a few days after flooding, surface water in treatment 3 showed the characteristic film of chalybeate waters and later brown iron oxide precipitated on the surface. Incidentally, the analysis of this soil gave 22 p. p. m. of soluble Fe and 13 p. p. m. of soluble Mn. The result may serve, at least in some measure, as an explanation of the fact that a scud shower after a spell of hot weather often can bring about serious crop damage in Tung-shan area.

Comparing the iron and manganese content of plants in table 10 with those of tables 8 and 9, it seems that those highest figures for iron in table 8 (0.2–0.26% Fe) may represent the toxic levels in rice plants of native varieties, about 2 months of age, whereas those highest analyses of manganese in the plants obtained from the affected farms in Tung-shan area are apparently below the toxic levels, which are assumably about 0.2% Mn for the same varieties of corresponding age. Examination of this data suggests that active iron, rather than manganese, is responsible for the crop failure in the field.

Experiment 2: After harvesting, the soils were stored in the greenhouse for subsequent study. The second pot experiment was carried on from July 19 to December 1, following the same treatments on the same pots in Experiment 1, except that manganese treated soil received 50 p. p. m. of Cu instead of Mn in this study. But in this experiment rice plants grew normally in all pots irrespective of the treatments. The soils had been kept dry and cracked for a period while stored in the greenhouse and this seems to have eliminated the injurious factor.

Experiment 3: The third pot experiment was set up to see the effect of various nitrogeneous fertilizers and liming along with those treatments as carried out in the preceding experiments. The soil was obtained from other seriously affected farms in Hsiang-ho village. 11 kg. of wet soil was placed in each pot and subjected to the following treatments:

No.	Treatments
1.	---Ns-P
2.	---Ns-P-K
3.	---Ns-P-K-Ca
4.	---Ns-P-K-Cu
5.	---Nn-P-K
6.	---Ns-P-Cu
7.	---Nc-P-K
8.	---Nc-P-K-Cu
9.	---Ns-P-K-Water drained and occasionally kept the surface soil dry and cracked, improving aeration.
10.	---Ns-P-K-Soil was air dried prior to flooding.

All the treatments, carried out in duplicate, received 0.6 gm. of nitrogen either supplied as ammonium sulfate (Ns), ammonium nitrate (Nn), or calcium cyanamide (Nc), and 0.6

gm. of P_2O_5 applied as superphosphate of lime. 0.6 gm. of K_2O was added as muriate of potash to each pot except for treatments 1 and 6. 10 gm. of $CaCO_3$ was added in treatment 3, and 2 gm. of $CuSO_4 \cdot 5H_2O$ was applied to treatments 4, 6, and 8. Calcium cyanamide was applied 10 days before planting. Three rice seedlings were planted to each pot on March 12, 1955 and the soils were kept water-logged during the growing period except in case of treatment 9. Plants were harvested on July 9 and the yield of rice grain was compared (table 11).

Table 11. Yield of Rice Grain as Influenced by Various Soil Treatments

No.	Treatment	Grain Yield (gm) per pot	Relative Yield Index (Control = 100)
1	Ns-P	18.3	100
2	Ns-P-K	16.9	92
3	Ns-P-K-Ca	13.9	76
4	Ns-P-K-Cu	20.0	109
5	Nn-P-K	14.5	79
6	Ns-P-Cu	23.8	130
7	Nc-P-K	16.7	91
8	Nc-P-K-Cu	19.3	105
9	Ns-P-K-aeration	19.0	104
10	Ns-P-K-Air dried soil	0	0

As shown in table 11, either potash fertilization or liming was without effect on the yield of rice grain, while copper sulfate apparently showed favorable effect either applied with ammonium sulfate or calcium cyanamide. No significant difference in the effect of nitrogen source was observed among the three forms used in this experiment, although ammonium nitrate appeared to be somewhat inferior to the others in its effect as commonly experienced in paddy fields. Beneficial effect was again obtained from soil aeration practice (Treatment 9). Soil drying ahead of flooding caused very stunted growth and the harmful effect appeared in a few days after flooding. Seedlings in one pot died on April 7, twenty-five days after transplanting. Plants in the other pot also died a few days later and a large amount of ferric hydroxide precipitated on the soils of both pots. When the plants died the iron precipitates were turned under and thoroughly mixed; rice seedlings from the reserved were again planted in the two pots without any further treatment. The new seedlings grew normally thereafter, even though the soils were still in a strongly reduced condition as evidenced by their characteristic musty odor. This fact pointed out that older rice seedlings are more tolerant than young ones to reduced iron in the soil.

Field Experiment

A field experiment consisting of various fertilizer treatments similar to those of the greenhouse studies was conducted along with the pot experiments in the first crop of 1955. The results were somewhat conflicting with those obtained from the greenhouse studies, possibly mainly due to the following reasons; 1) A farm ideal in all respcts could not be available. The farm selected for the experiment should be uniformly affected and without having been subjected to dry land cultivation in the preceding crop period. 2) The weather conditions were exceptionally favorable during the experiment and the soils were well dried to such an extent that the soil surface was cracked, which undoubtedly promoted good soil aeration rendering the effects of the various fertilizer treatments insignificant. 3) Sufficient acreage was not available to allow enough repetitions in field design. Although the result was not statistically significant, the best yield was obtained from those plots receiving complete fertilizers plus 100 kg. of copper sulfate per hectare. The rate of copper sulfate may be increased without causing any harmful effect because of the high fixing power of soil for copper.

General Discussion

As revealed in the field survey, soils in Tung-shan area generally have poor internal drainage as a result of high water table, which is often found within 2 feet of the surface of the affected farm even when the fields have just been drained. Consequently, microrelief has an important bearing upon the occurrence of crop injury.

The general tendencies observed in such soils on the growth of rice plants, as regards their characteristic symptoms or amelioration practice, have something in common with those of the degraded paddy soils in Japan, however, the actual cause of crop failure in each case is quite different. In the degraded paddy soils, iron and manganese are reduced to soluble form under flooding and leached down with percolating water resulting in iron and manganese deficiency. In poorly drained soils such as those of Tung-shan area, reduction of iron and manganese goes on under the same condition in the same way as in degraded paddies, however, poor drainage causes little movement of solution thus developing toxic concentrations of ferrous iron and other substances. This is especially true when the soils are high in organic matter. The toxicity of such soil is mainly due to several reduction products of which sulfides and ferrous iron are probably the most important. Considerable published evidence(3, 16) shows that ferrous iron appears to be toxic to most land plants in concentrations even as low as 1 to 5 p. p. m.

Considering the different soil forming process of the degraded paddy and poorly drained soils together with their common characteristic crop symptoms, it seems that neither the iron excess nor the iron deficiency but the reducing condition itself must be responsible for the sesame leaf spot disease.

Although significant response to potash was not obtained in the greenhouse studies, soil tests indicate that the soils are generally low in available potassium and there was evidence in the preliminary field trial that potash has favorable effect, increasing yield on such soils. Lawton(8)found that poorly drained soils generally have a greater need for potash fertilization than do well drained soils. The finding seems to be applicable to Tung-shan paddy soils. It is not clearly understood whether or not the depressed potash uptake is a result of the formation of certain double salts of iron and potassium, although plant analysis data indicate decreased iron uptake through potash fertilization. The beneficial effect of straw ash may be largely due to its supplying of potash to the soil. However, it seems that the effect might be partly due to the increase of SiO_2 since some published data (10) reveal that the diseased plants are generally low in SiO_2 content as compared to normal healthy plants.

Liming seems to be of little value on such soils for the control of iron toxicity as shown in table 11. Solubility of iron and manganese in paddy soils is, to a large measure, governed by oxidation-reduction potential rather than soil acidity; and in this connection liming may even cause adverse effect since it may promote decomposition of soil organic matter giving rise to more reduced conditions.

Copper has been proved effective on such soils. Although the beneficial effect of copper sulfate has been reported by numerous workers on soils high in iron and organic matter, some investigators (20) threw doubt upon its effect in poorly aerated soils. The results obtained in this study proved that copper sulfate can be used without fear to such soils; probably the effect would be somewhat less noticeable than that in aerated soils.

Very significant correlation between the degree of crop symptoms and iron content of the plants along with the favorable response to copper application confirmed the supposition that iron toxicity developed under poor drainage condition in Tung-shan paddy soils. Other toxic substances such as sulfides may also be responsible for crop injury.

Recommendations

The results of the greenhouse experiments reported here and of preliminary field study suggest the following measures for the prevention of serious crop damage in Tung-shan area:

1. Land drainage is absolutely necessary and is the only radical means of reclamation. Soils of the area are of loamy texture and provide fairly good potential internal drainage as indicated by permeability tests. Artificial drainage may be carried out either by ditching or tiling.
2. Soil dressing is also a very effective practice. However, this involves lots of difficulties in labor and expense, and is practically impossible on any large scale.
3. Heavy application of farm manure should be avoided unless the fields are well drained.
4. A crop rotation of rice and vegetables or sweet potatoes is recommended.

Summary

1. Field survey revealed that poor drainage as a result of high water table is the major detrimental factor to plant growth in Tung-shan area, and microrelief has an important bearing on crop injury.
2. Soil test indicates that Tung-shan soils are generally high in organic matter content and low in available potassium.

3. The toxicity of such soils is mainly due to some reduction products in the soil of which sulfides and ferrous iron are probably the most important. High correlation between crop symptoms and iron content of plants was obtained.

4. Toxicity of Fe^{++} is greater than that of Mn^{++} and older rice seedlings are more tolerant to iron excess than younger ones.

5. Greenhouse studies showed that water control practice and heavy dose of copper sulfate produced consistently greater yield than did the other fertilizer treatments. Liming appears to be of no effect on such soils.

6. Preliminary field trial indicates that the rice crop responded favorably to potash and copper fertilization.

7. A map was prepared showing the distribution of the farms affected together with their degree of crop damage using a 1/4800 base map.

8. General recommendations are given for the reclamation practice in the area.

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宜蘭縣冬山鄉“瀞酸稻田”之研究

（中文摘要）

李鴻基　　李蘭帝　　徐水泉

在宜蘭縣冬山鄉一帶水田有貧瘠不毛之現象，當地農民稱此種稻田曰「瀞酸田」，水稻於插秧後約一個月即開始受害，影響收穫量非淺。此類水田面積據此次調查約有二百公頃。本研究之目的即在探究其受害原因及提供其改良之方法。試驗工作內容包括下述三項：（1）田間調查。（2）土壤植物樣品及灌溉水之化驗。（3）溫室田間栽培試驗。

茲將各項工作分述如下：

田間調查：除製成受害稻田分佈圖以外，尙調查當地環境與作物受害之關係及當地農民對此種稻田所採補救之對策。其結果摘要如下：①受害水稻均患胡麻葉枯病，且其根之伸長亦受阻碍。②被害之發生在一期作插秧後1～2個月之間爲最顯著。③一期作若雨量愈少時則受害程度愈輕，此時之水田保持濕潤狀態，土面並生龜裂。此等水田在旱年卽使不施肥料亦可得相當之收穫。④熱天之驟雨對此等水田爲害很大，但一般健全水田則無此現象。⑤受害水田與健全水田，雖常相隣存在，但一般受害田比不受害田地勢稍低。⑥受害田中底層有礫層者，雖然其地下水位高而排水情形極劣，但其受害程度却較輕。⑦被害稻田附近水溝或田坡旁邊，常能見到紅棕色之鐵質沈積物。⑧含有氮磷鉀之化學肥料對此種稻田似無顯著效果。但據農民經驗稱：施用草木灰或可減輕其受害程度。⑨又據稱：若先行栽培旱作物則可遞減下一期稻作受害之程度。⑩客土爲根治此種毒害之有效辦法，但據農民稱：客土約一尺時方有效，因此對大面積受害田之客土實際上頗爲困難。⑪被害面積有逐年漸減之傾向。

土壤、植物樣品及灌溉水之化驗：由上述田間調查結果，推測其受害原因乃由於排水不良而生成之有害物質以致爲害作物，故化驗時亦曾注意此點而決定其分析項目。

土壤分析：分析項目有土壤反應、有機物、全氮有效性磷、鉀、導電度、熱鹽酸可溶性及水溶性鐵、錳，結果摘要如下：①有機物及氮磷含量較高，而鉀含量較低，且無過剩鹽分聚積現象。②各項土壤分析結果與受害程度無特別明顯之相關，惟土壤pH則以受害田爲較高，蓋因土壤之pH與其Eh（氧化還元電位）之間有相反之關係，pH高則Eh較低，Eh低表示土壤中還元狀態較强而使鐵、錳還元變爲可溶性，此等還元性物質大量存在時，將對作物產生毒害作用。

水分析：分析結果顯示地下水及瀞酸田附近溝水之鐵分含量較高。

植物分析：就氮、磷、鉀、鐵、錳五項成分加以分析，結果顯示受害水稻與未受害者之磷鉀含量並無顯著差異，而氮鐵錳之含量則以受害者爲高，受害水稻之鐵含量高達無害者之三乃至四倍，差異特別顯著。

溫室田間試驗：溫室盆栽試驗前後共施行三次，結果如下：①土壤放乾處理（保持濕潤狀態且上面生龜裂造成通氣）及硫酸銅之施用均有良好效果。處理放乾之狀態與現地乾燥時水田狀態相似，可見符合農民之經驗。②此種受害稻田土壤經風乾灌水後栽培水稻則有極大之爲害作用，甚至部份水稻因此受害致死。風乾後灌水之爲害與熱天驟雨之爲害相似。吾人推定此原因乃在此種土壤風乾後灌水，則有機物容易分解而促進還元作用之故。③盆栽試驗之植物體分析結果，顯示鉀與鐵之間略有頡抗作用。

田間試驗之各項處理，除排水放乾處理外，與盆栽試驗略同，但結果不顯著。因缺少理想試

驗田，且本年氣候極佳，爲近年來所罕見，一般受害程度較輕，而試驗之重複次數亦嫌過少，但最高收穫量仍在硫酸銅施用區。

砂耕試驗結果表示二價鐵比二價錳爲害較烈，且其毒害症候與田間者相似。

結論：所謂瀞酸田之爲害原因，是由於地下水位高而排水困難之水田中，多量有機物存在造成强烈之還元狀態，因此生成多量可溶性二價鐵及硫化物，對植物產生毒害作用之故。此種稻田之根本改良方法，爲設排水溝或排水管，使排水優良，惟目前似可以下列幾種對策補救之：①客土或作高畦補救排水不良。②少用堆肥少留藁稈，多用草木灰。③施行旱作與水稻之輪作。

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