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土壤特性對稻米品質之影響
(二) 土壤肥力對米飯食味之影響

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摘要：調查分析臺灣中部地區108個地點土壤及米質資料，利用米質優劣之差異進行各項土壤肥力因子對比。對比結果顯示，不論在總評、外觀、香味、口味、粘性、硬性等影響米飯食味品質因素中，土壤交換性鎂、鋅皆達極顯著差異，顯示土壤交換性鎂、鋅含量較低，生產之米飯食味均有較佳之趨勢。土壤全氮含量較低者，各項米飯食味皆顯著改善。另以米飯物性均衡度之優劣對土壤肥力因子進行對比，顯示全氮、交換性鎂、鈣、鋅含量較低之土壤，生產之米飯均衡度有較佳之趨勢。有機質含量較高之土壤，有助於生產均衡度較優之稻米。從土壤肥力管理觀點，減少氮肥施用，選擇交換性鎂、鈣、鋅含量較低土壤，並選擇施用高碳氮比的有機肥，可能有助於生產較高品質的良質米。

關鍵語：米質、食味、均衡度、土壤全氮、交換性鎂、鋅、有機質。

Effects of soil characteristics on eating quality of rice II. Quality and balance of cooked rice as affected by soil fertility

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Abstract. Field experiments including 108 paddy fields at central Taiwan were conducted to investigate the effect of soil fertility on rice eating quality. Data of the soil and the rice quality were analyzed, the differences of the soil properties between the two classes of rice quality, the better and the poorer one, were tested by linear contrast. It was showed that rice eating quality in appearance, aroma, flavor, clavor, cohesion, hardness and overall sensory evaluation, are significantly

affected by contents of exchangeable magnesium and zinc in soils. A lower soil exchangeable magnesium and zinc contents enhanced the eating quality of rice. Soils with lower total nitrogen contents also produced rice with high eating quality. Rice with the best balance (−H/H) by physical test were produced from soils with a lower nitrogen, exchangeable magnesium, calcium and zinc contents. Soils with higher organic matter also produced rice with higher balance. The results suggest that decreasing nitrogen fertilizer input, selecting soils with lower exchangeable magnesium, calcium and zinc contents, and applying organic matter with a higher carbon nitrogen ratio (C/N) are essential to high quality rice production.

Key words: Rice eating quality, Balance, Soil total nitrogen, Exchangeable magnesium, Zinc, Organic matter.

前　言

良質米生產除受到品種特性、氣候影響外，同時也受到土壤特性的影響。Chamuraet al. (1972)指出，土壤全氮含量過高，水稻生育後期氮肥吸收過量，容易造成水稻倒伏，千粒重下降，並使得米飯食味低劣。此外磷酸吸收係數較大的土壤，亦常造成米質不佳。米粒蛋白質含量與土壤氮素呈正相關，米粒蛋白質含量對質地食味指數（TPI）之影響呈二次曲線關係，亦即米粒蛋白質含量過高，將導致米飯食味低下（De Datts et al. 1972, Chikubu et al. 1983, Tamaki et al. 1989）。因此，過量的土壤氮素可能是造成米質低劣的主要土壤因素；至於其他土壤元素對米質的影響，則並不清楚。本試驗主要的目的在探討土壤肥力對稻米品質的影響，以為選擇良質米栽培土壤及肥培管理的依據。

材料與方法

自1989年二期至1992年一期，連續三年六個期作，調查並分析中部地區四個縣市，共108處地點之稻田土壤性質，及米質資料，以瞭解土壤性質，包含母質、肥力、化學、物理性質對米質的影響。本試驗探討土壤肥力的影響，水稻採用良質米品種—台農70號及臺中189號。

一、土壤肥力分析：

於水稻成熟期，進行田間土壤採樣，以土壤採樣管每處稻田逢機採20點以上，採表土0-20公分之土壤，採集之土樣充分混合均勻，並風乾磨碎過篩。肥力測定項目包括有機質（Walkley and Black 1934），全氮（Bremner 1965）、有效性磷（Olsen and

Sommers 1982）、交換性鉀、鈣、鎂（以1N NH_4OAc, pH7.0萃取，鉀以火焰光度計，鈣、鎂以原子吸光儀測定），銅、鋅（0.1N HCl萃取，原子吸光儀測定）。

二、米質分析：

米質分析由臺中改良場負責（Chen et al, 1994），試驗資料將米質區分爲較優、普通及較劣三組，將較優及較劣兩組之各項米質項目對各項土壤肥力進行對比，了解生產高品質良質米之土壤肥力分佈，以爲選擇良質米生產土壤，及肥培管理之參考。

結果與討論

一、土壤肥力對米飯食味綜合評鑑之影響

米飯食味優劣兩等級之對比顯示，全氮、交換性鎂、鋅含量較低之土壤，生產之稻米食味總評較佳（表一）。生產食味較優稻米之土壤，全氮平均爲1624ppm，交換性鎂爲479ppm，交換性鋅爲7.4ppm。而在生產食味較差稻米之土壤，其全氮含量平均爲1996ppm，交換性鎂、鋅分別爲821及9.3ppm，二者經對比結果皆達極顯著之差異。土壤氮素含量較高，促進水稻分蘗、穗粒數，穗重，進而提高產量（De Datta 1981），但相對提高稻穀蛋白質含量，並使米質低劣（Chamura 1972; Yamashita and Fujimoto 1974; Horino and Okamoto 1992）。此外，生產食味較優及較劣稻米之土壤，其有機質、有效性磷、交換性鉀、鈣含量之間並無明顯的差異，亦即此等土壤元素含量多寡，對米飯食味總評並沒有顯著的影響。

二、土壤肥力對米飯外觀的影響

食味品評中米飯外觀一項，以土壤全氮、交換性鎂、鋅含量低之土壤所生產的稻米表現最佳，對比結果皆優於含量較高之土壤所生產者（表二），並達到顯著差異。生產米飯外觀較佳之土壤全氮爲1700ppm，顯著低於生產外觀較差米飯之土壤（2008ppm）。交換性鎂爲512ppm、交換性鋅爲7.8ppm，亦較生產外觀較差米飯之土壤交換性鎂818ppm與交

Table 1. Overall sensory evaluation of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Overall sensory evaluation	Organic matter	N**	P	K	Ca	Mg**	Cu	Zn*
	(%)	ppm						
Good	2.8±0.1	1624± 88	31± 5	71±7	2952±326	479±60	8.7±0.7	7.4±0.5
Fair	3.1±0.2	1990±215	43±13	63±7	2862±757	297±84	8.8±1.2	7.5±1.1
Poor	2.7±0.2	1996± 87	34± 3	70±5	3603±373	821±50	7.7±0.5	9.3±0.6

*, ** indicate significantly different between ratings of "good" and "poor" at $\alpha=0.05$ and $\alpha=0.01$ by t-test, respectively. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control, "good" = rating of eating quality higher then the control, "fair" = rating equal to the control, and "poor" = rating lower than the control, respectively.

Table 2. Appearance of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Appearance	Organic matter	N*	P	K	Ca	Mg**	Cu	Zn*
	(%)				ppm			
>0	3.0±0.1	1700±101	31±5	66±6	2998±377	512±61	9.1±0.6	7.8±0.6
=0	2.6±0.4	1763±164	37±5	68±8	3729±896	635±70	6.6±1.0	5.9±0.9
<0	2.7±0.1	2008± 93	36±4	72±5	3418±358	818±57	7.9±0.6	9.6±0.7

*, ** indicate significantly different between ratings of ">0" and "<0" at $\alpha=0.05$ and $\alpha=0.01$ by t-test, respectively. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control.

換性鋅9.6ppm爲低。其餘土壤元素如磷、鉀、鈣含量較低者，亦有生產較佳外觀米飯之趨勢，但差異不顯著。土壤有機質含量高，對米飯外觀有正面的效果，生產米飯外觀較佳稻米之土壤，有機質平均含量爲3.0%，比之生產外觀較差稻米之土壤，有機質平均含量2.7%稍高，但對比結果並未達顯著差異。

三、土壤肥力對米飯香味的影響

米飯香味評估與食味總評、米飯外觀有相同的結果，除了土壤全氮未達顯著差異外，交換性鎂、鋅均有顯著影響。交換性鎂及鋅含量較低的土壤，生產之稻米香味有較佳之趨勢。交換性鎂含量較高，平均在865ppm，交換性鋅平均10.3ppm之土壤，生產之米飯香味較差。交換性鎂含量較低，平均514ppm，交換性鋅平均7.4ppm左右之土壤，米飯香味較佳（表三）。

四、土壤肥力對米飯口味的影響

土壤全氮、交換性鎂、鋅亦是影響米飯口味的重要因子，對比結果顯示，上述三者含量皆較低的土壤，生產之米飯口味皆優於對照（表四）含量平均爲1552ppm，交換性鎂414ppm，交換性鋅6.9ppm之土壤，生產之稻米口味較優；反之，全氮平均含量爲1999ppm，交換性鎂827ppm，交換性鋅在9.4ppm之土壤，生產之米飯口味較差。其他土壤肥力因子如有效性磷、交換性鈣含量較低之土壤亦有生產口味優良米飯之趨勢，土壤交換性鉀含量較高，生產之米飯口味亦有較佳之趨勢，但皆未達顯著水準。

五、土壤肥力對米飯粘性的影響

對米飯粘性而言，除了上述土壤全氮、交換性鎂、鋅均呈顯著差異外，交換性鈣亦是影響米飯粘性的重要因子（表五）。同樣地，這些土壤元素含量較低之土壤，生產之米飯粘性優於對照，其中全氮含量較低，平均爲1583ppm，交換性鈣2588ppm，交換性鎂、鋅分別爲382及6.9ppm之土壤，生產粘性較佳之稻米；反之，全氮含量較高平均2028ppm，交換性鈣爲3630ppm，交換性鎂爲834ppm，交換性鋅9.2ppm之土壤，生產之米飯粘性較差。

Table 3. Aroma of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Aroma	Organic matter	N	P	K	Ca	Mg**	Cu	Zn**
	(%)				ppm			
>0	2.9±0.2	1738±147	40±8	78±12	2825±325	514±87	8.7±0.9	7.4±0.7
=0	2.9±0.2	1693±103	32±4	67± 5	3286±508	571±53	7.1±0.7	6.8±0.6
<0	2.7±0.2	2069± 96	34±4	68± 5	3583±398	865±58	8.5±0.6	10.3±0.7

*, ** indicate significantly different between ratings of ">0" and "<0" at $\alpha=0.01$ by t-test. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control.

Table 4. Flavor of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Flavor	Organic matter	N**	P	K	Ca	Mg**	Cu	Zn**
	(%)				ppm			
>0	2.8±0.1	1552± 91	32±6	72±9	2905±338	414± 46	8.2±0.7	6.9±0.5
=0	3.1±0.3	2000±208	33±6	74±9	3367±716	674±105	8.7±1.3	8.0±1.3
<0	2.7±0.2	1999± 85	36±4	67±4	3520±374	827± 50	7.9±0.5	9.4±0.6

*, ** indicate significantly different between ratings of ">0" and "<0" at $\alpha=0.01$ by t-test. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control.

Table 5. Cohesion of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Cohesion	Organic matter	N**	P	K	Ca*	Mg**	Cu	Zn**
	(%)				ppm			
>0	2.9±0.1	1583± 89	29± 6	72± 7	2588± 280	382± 44	8.1±0.8	6.9±0.5
=0	2.4±0.3	1508±290	29±10	63±18	3444±1381	589±130	8.0±1.8	8.3±2.1
<0	2.7±0.1	2028± 81	37± 3	69± 4	3630± 350	834± 46	8.1±0.5	9.2±0.6

*, ** indicate significantly different between ratings of ">0" and "<0" at $\alpha=0.05$ and $\alpha=0.01$ by t-test, respectively. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control.

六、土壤肥力對米飯硬性的影響

米飯食味之硬性品評結果，全氮、交換性鎂、鋅含量較高之土壤，生產之米飯硬性有較高的趨勢（表六）。全氮含量較高，平均爲1959ppm，交換性鎂平均爲790ppm，交換性鋅平均爲9.0ppm之土壤，生產之米飯硬性較大；反之，養分含量較低，全氮平均1660ppm，交換性鎂465ppm，交換性鋅7.3ppm，生產之米飯硬性較小，可能較適合國人口味。其餘土壤肥力因子皆未達顯著差異。

七、土壤肥力對米飯均衡度的影響

Table 6. Hardness of cooked rice as affected by soil fertilities (2nd crop 1989～1st crop 1992).

Hardness	Organic matter	N*	P	K	Ca	Mg**	Cu	Zn**
	(%)				ppm			
>0	2.7±0.1	1959±82	36±3	69±4	3449±339	790±47	7.8±05	9.0±0.6
=0	2.8	2100	45	97	4459	747	9.2	8.3
<0	3.0±0.1	1660±89	30±6	68±7	2968±341	465±57	8.6±0.7	7.3±0.6

*, ** indicate significantly different between ratings of ">0" and "<0" at $\alpha=0.05$ and $\alpha=0.01$ by t-test, respectively. Ratings were evaluated by panel test in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control.

對米飯均衡度而言，除了土壤全氮、交換性鎂、鋅含量較低可獲得較佳米飯均衡度外，土壤有機質及交換性鈣含量亦爲影響均衡度之重要因子。生產均衡度較佳米飯之土壤有機質含量較高，平均爲2.9%，交換性鈣含量較低，平均爲2278ppm；反之，生產米飯均衡度較差之土壤，有機質含量較低，平均只有1.9%，交換性鈣則高達5507ppm。顯示土壤有機質含量高者，可能有改善米飯均衡度之效果（表七），但土壤交換性鈣太高則對米飯均衡度有不利的影響。選擇全氮、交換性鎂、鋅、鈣含量低的土壤，可望生產均衡度較佳之稻米，選擇有機質含量較高之土壤，或增施用有機質，可能有助於生產均衡度較佳之稻米。

綜合以上分析結果，顯示影響食味之重要土壤肥力因子爲全氮，交換性鎂、鋅，在各品評項目皆有一致的表現。此外，鈣與有機質亦影響米飯粘性及均衡度之表現。土壤全氮、交換性鎂、鈣、鋅含量過高，將導致稻米品質低劣。此一事實可能代表良質米栽培對土壤通氣的要求，由於排水通氣良好的土壤滲漏速率較高（Hwang, 1982），交換性鈣、鎂含量較低，有助於稻根活性的提昇，而改善米質，與本試驗結果吻合（Chen et al. unpublish data）。土壤有機質含量較高，對米飯均衡度有促進的效果，有機質對米質均衡度的貢獻，可能與改善土壤物理性質，因而促進根系的發展及養分的均衡吸收有關。因此，選擇新沖積土等肥力較低，氮素含量較低土壤，並選擇施用高碳氮比之有機質，如樹皮堆肥、穀殼等，將有助於生產高品質之水稻。

Table 7. Balance(−H/H) of cooked rice quality as affected by soil fertilities (2nd crop 1989～1st crop 1992).

−H/H	Organic** matter	N**	P	K	Ca**	Mg**	Cu	Zn*
	(%)				ppm			
B&C	2.9±0.1	1468± 72	24±3	67±7	2278±370	280±21	7±0.7	8±0.5
D	2.9±0.1	1980± 82	37±4	67±5	3301±319	705±35	8±0.5	8±0.5
E	1.9±0.2	1929±156	38±8	89±9	5507±368	1295±97	8±1.3	15±1.7

Classified by the range of −H/H, i.e. A:0.15-2.0, B:0.13-0.15, C:0.10-0.13, D:0.05-0.10 and E:<0.05, respectively (Okabe 1979). *, ** indicate significantly different between ranks(−H/H) of B&C and E at $\alpha=0.05$ and $\alpha=0.01$ by t-test, respectively.

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