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SOIL SICKNESS CAUSED BY CONTINUOUS CROPPING OF UPLAND RICE, MUNGBEAN, AND OTHER CROPS

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SOIL SICKNESS CAUSED BY CONTINUOUS CROPPING OF UPLAND RICE, MUNGBEAN, AND OTHER CROPS[1]

ABSTRACT

Eight years of studies of plots continuously cropped with upland rice and other crops have helped determine the mechanism of soil sickness. Continuous monoculture reduced growth and yield of rice, mungbean, and cowpea. Maize was slightly affected, and sorghum was not affected by continuous cropping.

Growth inhibition began with the second crop and increased with succeeding crops. Crop performance tended to improve slightly after extremely poor cropping seasons.

No soil sickness was observed in the rice – mungbean rotation. Detrimental effects of continuous cropping were more apparent at early growth stages in mungbean and cowpea and in later growth in upland rice. All four rices planted (IR2061-464-2-4, IR747-B2-6-3, IR5, and IR52) were affected.

Chemical analysis of the soil and response to fertilizer applications indicated nutrient status was not the direct cause of soil sickness. Root residue was a source of infection to the next crop in the monoculture. Sterilizing the sick soil and/or root residue removed the sickness, indicating that it is caused by microorganisms.

Nematodes did not contribute to upland rice soil sickness. They were, however, found in significant numbers in mungbean and cowpea, and an inoculation study suggested that nematodes increase the effect of soil sickness on leguminous plants.

Fungal activity for rice plants in continuously cropped plots differed from that in control plots. *Fusarium moniliforme* and an unidentified fungus with brown mycelia were most common in continuously cropped plots. Inoculation and fungicidal treatments, however, suggest that fungi were not the primary cause of soil sickness. Indications are that soil sickness is not caused by a single group of organisms.

Chloropicrin fumigation alleviated soil sickness most effectively for both upland rice and mungbean. Soil sickness in annual upland crops also can be avoided by proper crop rotation.

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SOIL SICKNESS CAUSED BY CONTINUOUS CROPPING OF UPLAND RICE, MUNGBEAN, AND OTHER CROPS

Reduction in growth and yield caused by continuous monocropping of the same land is called soil sickness, which is a general term that does not specify causal agents. Yield decline in continuous cropping may result from interwoven factors including buildup of soil-borne pathogens, depletion of mineral nutrients, and accumulation of toxic substances (allelopathy).

Growth inhibition in upland rice grown annually is well-known in Japan (Nishio and Kusano 1977). In the Philippines, growing legumes more than once a year reduces rice yields (IRRI 1975), causing farmers to be reluctant to plant legumes in rice-based rotations.

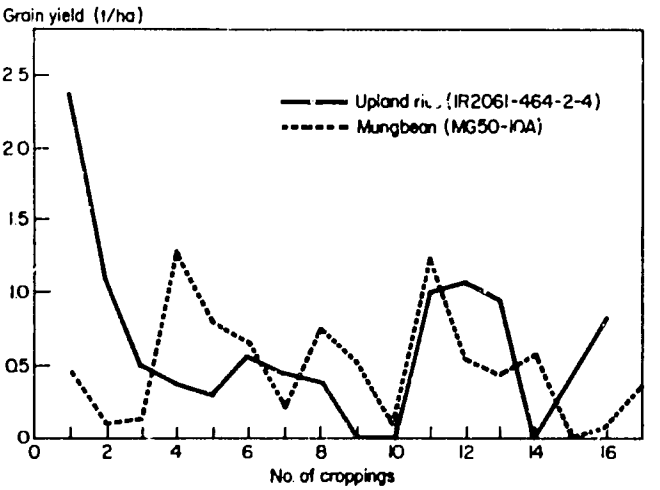
Recognized symptoms of soil sickness such as stunting leaf discoloration, and yield reduction are not crop specific. Therefore, the reduction in crop quality often is attributed to factors other than soil sickness and attempts are made to correct the symptoms by fertilization or other means rather than counteracting the sickness itself.

This paper summarizes our work on soil sickness of upland rice, mungbean, and other crops. It describes soil sickness effects (Ventura and Watanabe 1978), the possible involvement of nematodes (Ventura et al 1981) and fungi (Nishio et al 1980), and the interrelationship of various organisms that cause the growth inhibitory effects.

FIELD STUDIES ON CONTINUOUS CROPPING OF UPLAND RICE AND OTHER CROPS

Upland rice (IR2061-464-2-4 and IR747-B2-6-3 and, later, IR52 and IR5), maize, mungbean, cowpea, and sorghum were grown continuously in the same plots at IRRI from 1974 to 1982, except for maize, which was grown for 3 yr only. A continuous fallow plot was maintained as a check. Each was planted in 4 replications in 4.5- x 16-m plots in a randomized block design. Later, the plots were divided into subplots for rotation or fallow treatment, or for pesticide studies. Just before planting 100-60-60 kg NPK/ha was applied in rows for cereals and 20-60-60 NPK/ha was applied for legumes, unless otherwise indicated. High levels of cultural management and crop protection, including irrigation, weeding, and an insect and disease control program, were used.

Eight years of continuous monoculture caused different growth inhibitory effects for each crop. Figure 1 shows grain yield reduction in upland rice and mungbean. Yield usually declined 30-60%. In some cases, the crop failed. The oscillating yield pattern was clearer for mungbean than for upland rice. For both crops, growth reduction was uniform in the main plot. The inhibitory effects were particularly apparent at early growth stages for mungbean and cowpea and at later growth stages for rice (Ventura and Watanabe 1978). Table 1 compares the nonspecific symptoms of upland rice and mungbean soil sickness. IR2061-464-2-4 and IR747-B2-6-3 were affected, and IR52 and IR5, which



1. Grain yields in a continuous cropping pattern. IRRI field, 1975-81.

replaced the two earlier lines, had the same inhibitory effects (Table 2).

Maize and sorghum showed no definite symptoms on pattern of the inhibitory effect of continuous cropping (Ventura and Watanabe 1978). Differences among croppings may reflect seasonal variations in pest incidence.

Growth inhibitory effects were apparent in all 8 yr of continuous cropping. Table 2 shows yield reduction in continuous rice and mungbean as compared to first (formerly fallow) or rotation crops. Sorghum was not affected by soil sickness even after 7 yr. Maize appeared to be partially affected by soil sickness.

Root diseases (caused by *Sclerotium rolfsii* Sacc., *Pythium* sp., and *Corticium* sp.), which usually attack succulent seedlings, sometimes damaged cowpea and, to a lesser extent, mungbean. Root diseases affected specific areas

Table 1. Comparison of nonspecific symptoms exhibited by upland rice and mungbean soil sickness.

	Upland rice	Mungbean
Seed germination	Not affected	Affected
Seedling vigor and growth	Not affected	Severely affected
Plant population	Not affected	Affected (premature death of plants
Uniformity of growth	Uniformly inhibited	Uniformly inhibited
Plant height	Affected, effect increases with age	Affected more at early growth stage
Tillering	Affected sometimes	
Plant vigor	Usually, healthy plants up to 1 mo old, then plants become sickly and chlorotic	Sick plants tend to recover 1-½ mo after planting
Root weight	Not visibly affected	Affected sometimes
Straw weight	Affected	Affected
Grain number	Affected	Affected

Table 2. Effect of previous cropping condition on yield of upland crops. IRRI field.

Crop	Previous crop treatment	Grain yield[a] (t/ha)
Rice (IR2061-464-2-4)	3 continuous rice crops	0.36 b
	15 mo continuous fallow	1.75 a
Rice (IR52)	16 continuous rice crops	0.85 b
	2 yr continuous fallow	2.35 a
Rice (IR747-B2-6-3)	4 continuous rice crops	0.95 b
	4 continuous sorghum crops	1.55 a
Rice (IR5)	6 continuous rice crops	0.87 b
	7 continuous cowpea crops	3.02 a
Mungbean (MG50-10A)	8 continuous mungbean crops	0.53 b
	6 continuous sorghum crops	1.21 a
Mungbean (MG50-10A)	16 continuous mungbean crops	0.15 b
	2 mungbean + 1 yr fallow	0.60 a
Cowpea (EG green pod #2)	5 continuous cowpea crops	0.60 b
	5 continuous maize crops	1.64 a
Mungbean (MG50-10A)	16 continuous mungbean crops	0.42 a
	16 continuous cowpea crops	0.47 a
Sorghum (Cosor 2)	4 continuous sorghum crops	3.45 a
	4 continuous rice crops	3.71 a
Sorghum (Cosor 2)	16 continuous sorghum crops	2.95 a
	16 continuous cowpea crops	3.30 a
Maize (DMR2)	5 continuous maize crops	3.63 b
	5 continuous cowpea crops	4.47 a

[a]In crops of the same cropping period, means followed by a common letter are not significantly different at the 5% level.

in the plot and the effects differed from the uniform reduction in plant growth caused by continuous rice cropping.

To see if one rotation crop could eliminate harmful effects in a continuous cropping pattern, the rotation portion of the mother plot was again planted to the same continuous crop. One rotation crop of sorghum failed to reduce the harmful effects of soil sickness in upland rice (Table 3). Growth inhibitory effects in cowpea were partially corrected by one rotation crop of maize. In maize, one rotation crop of cowpea eliminated all the detrimental effects of continuous cropping. Sorghum had no visible response to crop rotation and continuous cropping.

A 3 yr rotation of upland rice and mungbean showed no growth inhibitory effects. Planting mungbean after cowpea caused soil sickness, which suggests similarities of growth inhibitory effects in leguminous crops.

The most susceptible crops were upland rice and mungbean. Keeping the field fallow for 5 mo in dry season improved growth and yield of both rice and mungbean in the continuous cropping pattern (Table 4, 5), and may be a partial cure, but even after 5 mo fallow, growth and yield were still inferior to those of rice and mungbean in rotation with cowpea or sorghum.

The second rice crop after 5 mo fallow in the continuous rice pattern and the second rice crop after 7 continuous cowpea crops had significantly decreased plant growth and yield (Table 4). The same was true of the second mungbean crop after 5 mo fallow in the continuous mungbean pattern and the second mungbean crop after 6 continuous sorghum crops (Table 5). This suggests early occurrence of growth inhibitory effects in rice and mungbean.

Before the first crop, pH of the Maahas clay soil was 6.2, with 0.13% total N. The pH rose slightly after 15 continuous mungbean crops, 13 upland rice crops, or 6 1/2 yr fallow. N level remained constant in continuous rice cropping but increased in fallow and continuous mungbean plots (Table 6). More P accumulated in mungbean than in rice plots. Because NPK were added for each crop, soil nutrient status may not be the primary factor in soil sickness.

ROOT RESIDUES AS A SOURCE OF INHIBITORY EFFECTS

Crop residues, especially roots left after harvest, may be the primary source of infection in succeeding crops (Nishio and Kusano 1975). Rice root residues were collected from the continuous rice plots, soil particles were removed by hand, and residues were placed immediately into a fallow plot in the same area. Some root residues were sterilized by steam at 110°C for 15 min. Chemical fertilization, seeding, and other cultural management were carried out as usual.

Dry matter weight of rice plants was significantly reduced when unsterilized root residue was added to healthy (fallow) soil (Table 7), and no reduction was observed when they were sterilized. Removing residue from continuously cropped soil did not reduce the inhibitory effect, probably because some of the root residues remained in the soil.

Table 3. Effect of one rotation crop on growth and yield in the continuous cropping pattern. IRRI field[a] (Ventura and Watanabe 1978).

Crop variety	Previous crop treatment	Maturity (d)	Plant ht (cm)	Grain yield (t/ha)
Upland rice IR747-B2-6-3	5 continuous IR747 crops	100	42 a	0.08 a
	1 sorghum after 4 continuous IR747 crops	100	43 a	0.09 a
Cowpea EG green pod #2	6 continuous cowpea crops	72	38 b	0.05 a
	1 maize after 5 continuous cowpea	72	61 a	0.65 a
Maize DMR-2	6 continuous maize crops	91	250 a	2.64 b
	1 cowpea after 5 continuous maize crops	91	248 a	4.45 a
Sorghum Cosor 2	5 continuous sorghum crops	92	168 a	6.10 a
	1 rice after 4 continuous sorghum crops	92	170 a	6.51 a

[a]For each crop, means followed by a common letter are not significantly different at the 5% level.

Table 4. Effect of previous cropping condition on growth and yield of upland rice. IRRI field[a] (Ventura and Watanabe 1978).

Cropping period, rice variety	Previous crop treatment	Plant ht (cm)	Dry matter wt (g/m²)	Grain wt (g/m²)
Jun-Sep 1976, IR2061-464-2-4	5 continuous rice crops	54 b	585 c	165 c
	5 mo fallow in the continuous rice pattern	61 b	772 b	214 b
	7 continuous cowpea crops	88 a	1265 a	446 a
Oct 1976-Feb 1977, IR2061-464-2-4	6 continuous rice crops	57 c	554 b	149 c
	1 rice crop after 5 mo fallow in the continuous rice pattern	59 c	742 b	117 bc
	1 rice crop after 7 continuous cowpea crops	68 b	1046 a	308 b
	8 continuous cowpea crops	81 a	1205 a	385 a
Jan-Jun 1977, IR5	7 upland rice crops	47 b		0 b
	2-1/2 yr of continuous fallow	63 a		127 a
	1 IR5 crop after 5 mo fallow in the continuous rice cropping pattern	44 b		0 b

[a]For every period in each column, means followed by a common letter are not significantly different at the 5% level.

To determine the effect of root residues on soil sickness, soil monoliths were taken at 18-cm depth from continuously cropped upland rice and continuously fallow plots. With minimum soil disturbance and air drying, the monoliths were placed, 3.5 kg/pot, in glazed porcelain pots. Pots received 100 ppm N, P_2O_5, and K_2O. Each treatment had five replications. Root residues from the sick plot were added to the healthy soil in proportion to the quantity

Table 5. Effect of previous cropping condition on growth and yield of mungbean MG50-10A. IRRI field[a] (Ventura and Watanabe 1978).

Cropping period	Previous crop treatment	No. of plants at 30 DAS (10^3/ha)	Plant ht (cm)	Dry matter wt (g/10 plants)	Grain yield (t/ha)
Jun-Sep 1976	8 continuous mungbean crops	170.5	39 c	100 a	0.53 b
	5 mo fallow in the continuous mungbean pattern	240.0	60 b	152 a	1.11 a
	6 continuous sorghum crops	254.0	81 a	140 a	1.21 a
Oct 1976-Feb 1977	9 continuous mungbean crops		37 b	75 b	0.09 c
	1 mungbean crop after 5 mo fallow in the continuous mungbean pattern		39 b	99 b	0.16 bc
	1 mungbean crop after 6 continuous sorghum crops		58 a	140 a	0.23 b
	7 continuous sorghum crops		78 a	161 a	0.45 a

[a]For every period in each column, means followed by a common letter are not significantly different at the 5% level.

Table 6. Effect of continuous cropping on nutrient status of upland rice.

Soil analysis[a]	6 continuous upland rice crops	13 continuous upland rice crops	2.5 yr continuous fallow	6.5 yr continuous fallow	15 continuous mungbean crops
pH (1:1 wt/vol H_2O)	6.1	6.4	6.0	6.4	6.25
EC (mmho, wt/vol H_2O)	0.31	0.20	0.28	0.14	0.25
Exchangeable cations (meq/100 g ads)[b]					
Na	1.2	0.98	1.1	1.2	0.85
K	0.8	0.99	1.0	1.2	1.68
Mg	7.5	7.8	6.2	8.2	7.0
Ca	16.2	16.7	14.5	16.0	16.1
Total Exchangeable bases (meq/100 g ads)	25.8	24.7	22.9	26.5	23.1
Available P (ppm)	13.0	26.0	15.0	n.d.	26.6
Total N (%)	0.13	0.13	0.13	0.16	0.16
Organic C (%)	1.23	1.11	1.25	1.17	1.12
Total elements (ppm)					
P	534	529	645	726	1158
K	1354	1262	1536	1110	1453
Mg	4177	3730	4188	3885	3730
Cu	168	133	167	135	133
Mn	2565	2291	2716	2130	2304
Zn	126	124	131	119	124
Fe (%)	9.14	11.1	9.15	11.8	11.9
CEC (meq/100 g ads)		29.6		26.5	29.4

[a]Taken after harvest of the crop. [b]ads = air dried soil.

Table 7. Effect of root residue of upland rice on growth and dry matter weight on upland IR2061-464-2-4, IRRI field, 1978 dry season.[a]

Crop history	Root residue treatment	Plant ht (cm)	Total dry matter wt (g/m²)
4 yr fallow	None	51 a	127 a
	Sterilized roots added	52 a	123 a
	Unsterilized roots added	47 a	103 b
10 continuous rice crops	Root residues removed[b]	34 b	70 c
	Root residues retained	36 b	85 bc

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Root residues from 4.5 m² of the continuous rice plot, gathered and transferred to another plot of the same size.

Table 8. Effect of soil sterilization and root residues on the soil sickness of upland rice, IRRI greenhouse.

Soil condition	Soil sterilization[a]	Root stubble treatment	Total dry matter[b] (g/pot)
Sick soil	+	Removed	48.6 a
Sick soil	+	Retained, sterilized	46.4 a
Sick soil	–	Retained, unsterilized	15.8 c
Sick soil + benomyl and thiram	–	Retained, unsterilized	14.9 c
Healthy soil	+	No addition	44.8 a
Healthy soil	+	Unsterilized roots added	33.9 b

[a]+ or – mean sterilized or unsterilized. [b]Means followed by a common letter are not significantly different at the 5% level.

of residues in the field. Soil and root residues were sterilized by γ-ray irradiation from ^{60}Co for 20.5 h to reach 5 megarad.

Results from pot culture were similar to those observed in the field (Table 8). Adding unsterilized roots to healthy soil caused some degree of growth inhibition. Sterilizing sick soil and root residues increased plant dry matter weight threefold. Adding fungicide (10 kg benomyl and 2 kg thiram ai/ha) before sowing seeds did not improve plant growth.

In mungbean, two pot culture trials similar to the upland rice trials were conducted, except that each pot received 40 ppm N and *Rhizobium* spp. was inoculated just before sowing. In the first mungbean trial, seeds did not germinate when unsterilized mungbean root residues were present, but with no residue there was complete germination. Sterilizing mungbean soil or root residues gave 100% germination. In the second trial, soil sickness did not inhibit mungbean germination.

Plants grew better in fallow and upland rice soils than in the continuous mungbean soil (Table 9), and adding unsterilized root residues to the fallow soil did not clearly inhibit plant growth. As in the field trials, sick mungbean tended to recover at later growth stages. Two weeks of flooding or drying of sick soil did not reduce the harmful effects of soil sickness, perhaps because the pretreatment period was too short. In a related study, drying the soil for 30 d or longer significantly increased grain yield of mungbean and bush sitao (IRRI 1975).

Table 9. Effect of root residues and soil pretreatment on growth and yield of mungbean, IRRI greenhouse, Oct 1976-Jan 1977[a] (Ventura and Watanabe 1978).

Field cropping condition	Soil treatment	Plant ht (cm)	Grain (g/pot)
9 continuous mungbean crops	None	25 c	1.2 e
	2 wk flooding	25 c	2.2 de
	2 wk air-drying	16 d	1.0 e
27 mo continuous fallow	None	30 ab	3.6 bc
	Unsterilized roots added	28 b	2.9 bc
	Sterilized roots added	29 b	4.3 ab
6 continuous upland rice crops	None	33 a	5.5 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level.

The cause of soil sickness in legumes definitely is different from that in upland rice because a rice - legume rotation did not show inhibitory effects. However, in both crops root residues were the primary source of infection, and sterilization studies strongly indicated microorganism involvement. It is likely that presence and quantity of crop residues are related to the appearance of growth inhibitory effects. Under the normal 2-crop sequence, inhibitory effects became more apparent at mungbean seed germination and seedling stage and tended to diminish at later stages, as root residues decomposed. This may be why one fallow season significantly reduces soil sickness in mungbean. It is the reverse for upland rice because rice residue decomposes much slower.

When mungbean growth is poor, only a small amount of crop residue remains in the soil and the following crop is better. In upland rice, which has relatively more root residue, growth improves after two crops with almost no grain yield.

EFFECT OF FLOODING ON DEVELOPMENT OF SOIL SICKNESS

An experiment was conducted to determine the effect of one lowland rice crop on soil sickness. Soil from the continuous upland rice plot was put in pots (3 kg/pot, 4 replications) and fertilizer equivalent to 100-60-60 kg NPK/ha was added before planting. IR2061-464-2-4 was grown for three seasons. In season 1, both sick soil treatments were planted to upland rice. In the second cropping, pots of sick soil were puddled, flooded, and planted with lowland rice. After harvesting the lowland crop, the flooded soil was allowed to dry to field moisture capacity, and then prepared for upland rice. All treatments were planted to upland rice in the third cropping.

Plant growth was uniform in the first crop, suggesting uniform soil sickness effects (Table 10). In the second crop, lowland rice performed better than upland rice, which had markedly reduced yield. One flooded crop did not, however, remove the inhibitory effects of continuous cropping. Per-

Table 10. Effect of upland-lowland farming rotation on upland rice soil sickness. IRRI greenhouse, 1978 dry season to 1979 dry season.

Previous cropping conditions	Present soil condition and crop	Plant ht[a] (cm)	Dry matter wt[a] (g/pot)
	1st greenhouse crop		
8 continuous rice crops (field)	Upland rice	60.0 a	21.0 a
8 continuous rice crops (field)	Upland rice	58.7 a	21.3 a
4 yr fallow	Fallow	–	–
	2d greenhouse crop		
9 continuous rice crops	Upland rice	64.4 b	9.0 b
9 continuous rice crops	Lowland rice	90.9 a	23.9 a
Continuous fallow	Fallow	–	–
	3d greenhouse crop		
10 continuous rice crops	Upland rice	63.0 b	19.8 b
9 upland rice + lowland rice	Upland rice	63.0 b	19.6 b
Continuous fallow	Upland rice	69.8 a	45.1 a

[a]For every period in each column, means followed by a common letter are not significantly different at the 5% level.

haps, the inhibitory agents survived such duration and conditions and became active again when the soil returned to upland.

NEMATODES AND SOIL SICKNESS

Nematode buildup was found to relate to upland rice soil sickness in Japan (Nishizawa et al 1971). In the Philippines, large populations of the reniform nematode *Rotylenchulus reniformis* were found in field legumes (Castillo et al 1977) and may reduce mungbean growth and yield in continuous cropping. Nematode population was studied (Castillo et al 1977-78) in experimental field plots and pot culture.

Results from two successive cropping seasons suggested that nematodes do not contribute to upland rice soil sickness (Table 11). No appreciable nematode population was found 1 mo after planting or at flowering stage. Nematodes were not found in feeding position on or in the roots. Population density of *Rotylenchulus* and *Helicotylenchus* decreased during flowering, a trend contrary to the appearance of the growth inhibitory effects toward rice maturity. Dense populations of root-infecting nematodes were found in the continuous mungbean plot, but rice-after-mungbean suppressed the population.

Although the 4- to 8-wk interval between crops appreciably reduced nematode population in continuous mungbean plots, population was still significantly higher than that in other cropping patterns (Table 12), and may influence the poor growth and death of young mungbean plants (Table 13). It was hypothesized that poorer seedling growth and smaller mungbean plant population in continuously cropped mungbean plots accounted for the comparatively lower nematode population in those plots than was in rice – mungbean rotation plots at flowering and maturity.

Rotylenchulus was the predominant nematode genus. Examination of stained roots showed *Rotylenchulus* females and a few *Meloidogyne* in feeding position.

Grain yield was significantly lower in the continuous mungbean plots than in the previous fallow and rice – mungbean rotation plots (Table 13). Despite taller and denser plant populations, the rice – mungbean rotation produced grain yield similar to that produced after fallow, perhaps because of a high pathogenic nematode population in the rotation.

Table 11. Plant parasitic nematodes in soil from continuous upland rice (IR2061-464-2-4) and mungbean (MG50-10A) plots. IRRI field, 1978 wet and 1979 dry season (Ventura et al 1981).

Crop history	Present crop	Nematode density[a] (mean no./300 ml soil + 1 g roots)				Rice grain yield (t/ha)
		Rotylenchulus	*Meloidogyne*	*Helicotylenchus*	Total of 7 genera[b]	
			1978 wet season, 1 mo after planting			
14 continuous mungbean crops	Mungbean	263 a	1 a	4 a	272 a	
1 yr fallow	Rice	5 a	0 a	44 a	49 b	
1 rice crop + 1 mungbean crop	Rice	24 b	0 a	35 a	59 b	
10 continuous rice crops	Rice	0 b	0 a	9 a	9 b	
			Flowering stage			
14 continuous mungbean crops	Mungbean	907 a	45 a	5 a	960 a	
1 yr fallow	Rice	0 b	0 b	64 a	67 b	1.9 a
1 rice crop + 1 mungbean crop	Rice	1 b	0 b	2 a	3 b	2.0 a
10 continuous rice crops	Rice	1 b	0 b	19 a	20 b	1.0 b
			1979 dry season, 1 mo after planting			
11 continuous rice crops	Rice	2 a	0	22 a	24 a	
1 yr fallow	Rice	1 a	0	19 a	21 a	
1 yr fallow	Fallow	0 a	0	21 a	26 a	
			Flowering stage			
11 continuous rice crops	Rice	0	0	3 a	7 a	1.1 b
1 yr fallow	Rice	0	0	2 a	2 a	1.7 a
1 yr fallow	Fallow	0	0	1 a	1 a	

[a]For each season and growth stage, means in a column followed by a common letter are not significantly different at the 5% level. [b]*Rotylenchulus, Helicotylenchus, Meloidogyne, Tylenchorhynchus, Hemicycliophora, Hemicriconemoides,* and *Criconemoides.*

Table 12. Effect of the previous crop on plant parasitic nematodes of mungbean. IRRI field, 1979 dry season (Ventura et al 1981).

Crop history	Present	Nematode density[a] (mean no./300 ml soil + 1 g roots)		
		Rotylenchulus	*Meloidogyne*	Total of 5 genera[b]
		Two wk after planting		
15 continuous mungbean crops	Mungbean	73 a	0	78 a
1 yr fallow	Mungbean	3 b	0	17 b
Rice - mungbean - rice (rotation)	Mungbean	12 b	0	22 b
		Flowering stage		
15 continuous mungbean crops	Mungbean	1250 b	3 a	1255 b
1 yr fallow	Mungbean	19 b	3 a	40 b
Rice - mungbean - rice (rotation)	Mungbean	3319 a	33 a	3370 a
2 yr fallow	Fallow	27 a	1 a	42 b
1 yr mungbean and 1 season fallow	Mungbean	407 b	21 a	447 b
		Maturity[c]		
15 continuous mungbean crops	Mungbean	603 b	3 a	607 b
1 yr fallow	Mungbean	440 b	111 a	554 b
Rice - mungbean - rice (rotation)	Mungbean	1707 a	48 a	1761 a
2 yr fallow	Fallow	2 b	1 a	4 b
1 yr mungbean and 1 season fallow	Mungbean	268 b	2 a	271 b

[a]For each growth stage, means in a column followed by a common letter are not significantly different at the 5% level. [b]*Rotylenchulus, Meloidogyne, Helicotylenchus, Tylenchorhynchus,* and *Criconemoides.* [c]56 days after planting.

The nematode density was very low in the third cropping season, even in the continuous mungbean plots, at 2 wk after planting (Table 14), probably because of the abundant rain (about 600 mm from 20 May to 14 Jul 1979) during this period. Generally, the nematode population increased steadily during the flowering and maturation periods, although the densities were much lower than during the previous season. Lower nematode population in monoculture mungbean that season, as compared to that in the preceding cropping season, probably accounted for the grain yield increase. These findings suggest the involvement of nematodes in mungbean soil sickness. The nematode population dynamics in the continuous mungbean, cowpea – mungbean, and continuous cowpea plots were similar. It is possible that soil sickness in the two crops was also similar.

A pot experiment was conducted to confirm the involvement of nematodes in mungbean soil sickness. For the first cropping, the pots with the continuously cropped soil were planted with mungbean MG50-10A. Pots with the fallow soil were not planted.

After harvest, to sterilize soil with minimum disturbance to soil chemical properties, pots were exposed to 20.5 h of γ-ray irradiation from ^{60}Co to reach 5 megarad and pesticide tests were conducted. Mungbean seeds were inoculated with *Rhizobium* spp. before planting. One week after planting, 77 egg masses of *R. reniformis* and 1 egg mass of *M. incognita,* freshly taken from mungbean roots in the field, were introduced into the seedling root zone. The average number of eggs per egg mass was 65 in *R. reniformis* and 275 in *M. incognita.*

Nematode densities were similar in unsterilized sick soils before planting (Table 15). Irradiation by γ-ray killed all *Rotylenchulus* and *Meloidogyne,* and fallow or healthy soils remained nematode-free.

Exposing the sick soil to γ-ray irradiation raised mungbean yield to equal that in healthy soil (Table 15). Treatment with nemacur killed most, if not all, nematodes and eliminated inhibitory effects.

Introducing *Rotylenchulus* and *Meloidogyne* to the irradiated sick soil presumably reduced grain yield to the level of the untreated sick soil. However, adding nematodes to untreated healthy soil did not reduce yield, indicating that nematodes do not necessarily inhibit growth.

Despite high nematode population, grain yield was improved by applying fungicides to unsterilized sick soil, in-

Table 13. Effect of the previous crop on growth and yield of mungbean (MG50-10A). IRRI field, 1979 dry season[a] (Ventura et al 1981).

Crop history	Plant ht (cm)			Plant population (x 10^3/ha)			Grain (kg/ha)
	4 wk	6 wk	8 wk	4 wk	6 wk	8 wk	
15 continuous mungbean crops	11.4 a	11.8 c	24.1 d	221.0 a	97.6 c	63.5 c	61.5 d
2 yr fallow	13.2 a	19.5 a	36.7 c	263.4 a	185.3 b	158.3 b	419.6 a
1 rice crop - 1 mungbean crop - 1 rice crop	13.3 a	24.5 ab	50.1 a	284.1 a	263.0 a	228.0 a	473.1 a
1 yr mungbean and 1 season fallow	13.4 a	19.2 b	43.1 b	270.5 a	209.8 b	190.3 ab	514.7 a

[a]In a column means followed by a common letter are not significantly different at the 5% level.

Table 14. Effect of the previous crop on plant parasitic nematodes and on yield of mungbean and cowpea. IRRI field, 1979 wet season (Ventura et al 1981).

Crop history	Present crop	Nematode density[a] (mean no./300 ml soil + 1 g roots)			Grain yield (kg/ha)
		Rotylenchulus	*Meloidogyne*	Total of 4 genera[b]	
		2 wk after planting			
16 continuous mungbean crops	Mungbean	2 a	1 a	3 a	
2 years fallow	Mungbean	0 a	1 a	1 a	
16 continuous cowpea crops	Mungbean	6 a	0 a	6 a	
1 yr fallow and 1 crop mungbean	Mungbean	2 a	0 a	3 a	
2 yr fallow	Fallow	1 a	0 a	2 a	
16 continuous cowpea crops	Cowpea	29 a	0 a	29 a	
		Flowering stage			
16 continuous mungbean crops	Mungbean	35 bc	0 b	35 bc	
2 yr fallow	Mungbean	1 c	0 b	1 c	
16 continuous cowpea crops	Mungbean	74 a	23 a	97 a	
1 yr fallow and 1 crop mungbean	Mungbean	22 bc	5 b	27 bc	
2 yr fallow	Fallow	0 c	0 b	0 c	
16 continuous cowpea crops	Cowpea	54 ab	5 b	60 ab	
		Maturity[c]			
16 continuous mungbean crops	Mungbean	251 a	7 ab	258 a	422 b
2 yr fallow	Mungbean	36 c	0 c	36 c	879 a
16 continuous cowpea crops	Mungbean	169 b	4 b	173 b	472 b
1 yr fallow and 1 crop mungbean	Mungbean	10 c	5 b	15 c	820 a
2 yr fallow	Fallow	1 c	0 c	1 c	No crop
16 continuous cowpea crops	Cowpea[d]	56 c	11 a	67 c	41

[a]For each growth stage, means in a column followed by a common letter are not significantly different at the 5% level. [b]*Rotylenchulus, Meloidogyne, Helicotylenchus,* and *Tylenchorhynchus.* [c]54 days after planting. [d]Cowpea not included in grain yield analysis of variance, being a different crop.

dicating the possible involvement of fungi in soil sickness.

The appearance of inhibitory effects in continuously cropped soil and when nematodes or fungi are present may indicate that other factors in the monoculture soil interact with these two groups of organisms. Interaction of nematodes with fungi or other microorganisms is suspected.

Table 15. Plant parasitic nematodes just before chemical treatment and sowing of seeds and after harvest of mungbean (MG50-10A) as affected by irradiation, nematicide and fungicide, and nematode addition. IRRI greenhouse, 1979 wet season (Ventura et al 1981).

Crop history	Soil treatment	Nematode density[a] (mean no./300 ml soil + 1 g roots)			Grain yield (g/pot)
		Rotylenchulus	*Meloidogyne*	Total of 4 genera[b]	
		After soil irradiation (if required) and before application of chemicals and planting			
16 continuous mungbean crops (sick soil)	None	96 a	0	96 a	
	Nemacur to be added	86 a	0	87 a	
	Soil irradiated	0 b	0	1 b	
	Nemacur, furadan, and benomyl/thiram to be added	62 ab	0	62 ab	
	Benomyl/thiram to be added	81 a	0	81 a	
	Soil irradiated and nematodes to be added	0 b	0	0 b	
5.5 yr fallow (healthy soil)	Nematodes to be added	0 b	0	0 b	
	None	0	0	4 b	
		After harvest			
17 continuous mungbean crops (sick soil)	None	700 b	32 a	732 b	3.3 c
	Nemacur added	13 c	10 bc	23 c	6.9 ab
	Soil irradiated	2 c	0 c	2 c	6.6 b
	Nemacur, furadan, and benomyl/thiram added	5 c	16 b	21 c	6.3 b
	Benomyl/thiram added	501 bc	37 a	538 bc	6.2 b
	Soil irradiated and nematodes added	699 b	9 bc	709 b	3.0 c
5.5 yr fallow (healthy soil)	Nematodes added	1395 a	0 c	1416 a	9.0 a
	None	6 c	0 c	7 c	6.2 b

[a]For each growth stage, means in a column followed by a common letter are not significantly different at the 5% level. [b]*Rotylenchulus, Meloidogyne, Helicotylenchus,* and *Tylenchorhynchus.*

FUNGI ON UPLAND RICE ROOTS IN CONTINUOUSLY CROPPED FIELDS

There was a strong indication of microorganism involvement in upland rice soil sickness. Fungi are the most probable cause of soil-borne diseases. If fungus is a causal agent, it should be more abundant on and in roots of the affected plants.

The fungal genera on the root surface of upland rice was determined by planting washed root segments on several kinds of agar plates, then incubating at room temperature (25-30°C) for 4-10 d. Most of the fungi isolated were considered to have been present on the root surface not as spores but as active mycelia. The frequency of occurrence of each genus was expressed as the fungal activity: the total number of isolates of each genus divided by the total number of segments planted, times 100. Table 16 shows the abundance of *Fusarium* and the sterile forms. In Japan, the dominant genera are *Fusarium*, *Pyrenochaeta*, *Pythium*, and the sterile forms (Nishio and Kusano 1977, Nishio and Kusano 1979). *Pyrenochaeta* has been positively identified as being involved in the soil sickness of upland rice (Nishio and Kusano 1979). It was not observed, however, in the soil sickness plots of IRRI.

The sterile fungi (brown mycelia) tended to increase with continuous cropping, which agrees with microscope observations of the increasing length of grown mycelia (Table 17), and suggests involvement of an unidentified brown mycelia fungus (or fungi) in upland rice soil sickness. Brown mycelia fungi increased in length 10 times during an additional 30-d cultivation, septated; and some penetrated into the cortex and stele.

Fusarium flora on or in upland rice roots in sick soil was compared with that on healthy plants. The flora was estimated by frequency of occurrence of *Fusarium* species isolated from washed upland rice roots using Komada's *Fusarium*-selective medium enriched with 0.25 g chloramphenicol/liter. The species composition of *Fusarium* was distinctly influenced by cropping history (Table 18). *Fusarium moniliforme* was predominant on roots of continuously cropped rice, suggesting its involvement in soil sickness of upland rice.

The survival of *F. moniliforme* in field soil was determined by gathering root residue 4 wk after harvest, washing the root residue segments with sterilized deionized water, and planting in a *Fusarium*-selective medium enriched with 0.25 g chloramphenicol/liter. The common period of time between two cropping seasons enabled the fungus to survive in the plant residues (Table 19).

Table 16. Frequency of occurrence of fungi isolated from washed root segments of upland rice (47 days old) using Czapek-Dox agar medium (Nishio et al 1980).

Fungal genus	Fungal activity[a]		
	Control plants		Continuously cropped plants
	Plot a	Plot b	
Fusarium	23.3	9.8	12.9
Curvularia	0.8	3.6	0.8
Monocillium	3.3	3.6	3.0
Aspergillus	1.7	0.9	0
Penicillium	1.7	0	0
Other genera[b]	0	1.8	0.8
Sterile hyaline	38.3	33.0	24.2
Sterile brown	18.3	21.4	31.8
Unidentified	2.5	0.9	0
Segments planted (no.)	120	112	132
Total no. of isolates	109	84	97
Segments colonized (%)	87.5	71.4	72.7

[a] Fungal activity = $\frac{\text{total no. of isolates of each genus}}{\text{total no. of segments planted}} \times 100$.

[b] Other genera included *Cephalosporium*, *Cylindrocarpon*, *Mucoraceae*, and *Trichoderma*.

Table 17. Mycelial length on roots of upland rice as determined microscopically (Nishio et al 1980).

Mycelia	Mycelial length[a] (mm/mm²)			
	17 days after sowing		47 days after sowing	
	Control plants	Continuously cropped plants	Control plants	Continuously cropped plants
Brown	0.73	0.33	0.80	3.61
Hyaline	2.38	1.86	1.17	3.85
Total	3.11	2.19	1.97	7.46

[a] Mycelial length was determined by observing 288 microscopic fields (= 8 plants × 3 roots × 12 microscopic fields).

Table 18. Frequency of occurrence of *Fusarium* isolated from washed root segments of upland rice using selective medium (Nishio et al 1980).

	Fungal activity[a]	
	Control plant[b] (Plot 2a)	Continuously cropped plant[b] (Plot 1a)
F. oxysporum	18.1 (83.3%)	2.5 (11.5%)
F. solani	1.7 (7.4%)	1.7 (7.7%)
F. moniliforme	2.1 (9.2%)	17.5 (80.8%)
Segments planted (no.)	240	240
Total no. *Fusarium* isolated	54 (100.0%)	52 (100.0%)
Segments colonized (%)	22.0	20.4

[a] $\frac{\text{Total no. of isolates of each genus}}{\text{total no. of segments planted}} \times 100$.

[b] 47 days after sowing.

Table 19. Survival of *F. moniliforme* on root residues in field soil.[a]

Fusarium oxysporum	1.1[b] (3.0%)
Fusarium solani	8.8[b] (26.6%)
Fusarium moniliforme	26.4[b] (72.7%)
No. of segments planted	247
Total *Fusarium* isolated	33 (100%)
Segments colonized (%)	12.0

[a] Taken from plots of continuous rice crop, 4 wk after harvest. [b] Expressed as fungal activity.

Table 20. Involvement of *Fusarium moniliforme* in soil sickness of upland rice. IRRI greenhouse.

Soil condition	Root residue[a]	*F. moniliforme* culture[a]	Total plant dry wt (g/pot)	*F. moniliforme* isolated[b]
Sick soil,	–	–	23.8	0.0
sterilized[c]	+	–	18.4	0.0
Sick soil,	–	–	14.1	45.7
unsterilized	–	+[d]	17.7	78.4
Healthy soil,	–	–	18.1	0.0
sterilized[c]	–	+	22.8	92.3
	–	+ (sterilized)	21.7	4.7
	+	–	16.5	0.0
	+ (sterilized)	–	20.0	0.0

[a]– = absent, + = added. [b]*Fusarium* flora was estimated by frequency of occurrence of *Fusarium* species isolated from washed root of upland rice using Komada's *Fusarium*-selective medium. [c]Sterilized with chloropicrin at 0.5 ml/pot (injected at 10-cm depth). [d]A *F. moniliforme* isolated from upland rice root was cultured on soil-wheat bran medium for a month. Before seeds were sown, each pot received 200 g (30% H_2O content) of the culture.

The role of *F. moniliforme* in soil sickness of upland rice was studied in pot culture in the greenhouse. A *F. moniliforme* isolate from upland rice roots taken from the continuously cropped plot was cultured on soil-wheat bran medium for 1 mo. Before sowing rice seeds in the pot, 200 g of the culture (fresh weight, about 30% water content) was mixed with the soil. As in earlier experiments, adding unsterilized root residues to sterilized sick and healthy soil decreased total dry matter weight of rice plants (Table 20). However, adding a pure culture of *F. moniliforme* did not clearly inhibit rice plant growth despite the large number that survived in the soil. It was noticed, though, that plants in unsterilized sick soil, without inoculation, had the lowest dry matter weight and a high population of this *Fusarium* species. There is no doubt about the pathogenic potentialities of *F. moniliforme*, but these results indicate that it is not the primary cause of upland rice soil sickness, although it may increase soil sickness initiated by other microorganisms in the root residues.

PESTICIDE TREATMENTS

To better understand soil sickness, the plots continuously cropped for 8 yr were divided into 4.5- × 1.5-m subplots, with a 1-m buffer strip between plots. Pesticides were applied to control target organisms (Table 21).

In upland rice, pesticides applied to the soil before planting did not affect the growth and yield of plants in the healthy or formerly fallow plots (Table 22), indicating that the microorganisms that were killed did not have a significant pathologic effect on upland rice. Chloropicrin fumigation eliminated inhibitory effects in continuously cropped plots and they yielded equal to healthy soil plots. Because of high variability among replications, the specific-acting validacin and wide-spectrum benomyl did not significantly improve growth and grain yield.

As in upland rice, soil fumigation and pesticide application did not affect plant growth and yield of mungbean in healthy or former sorghum plots (Table 23). In the continuously cropped plots, chloropicrin improved plant growth, although some inhibitory effects were observed at early growth stages. Fungicides partially improved plant growth, which supported earlier findings that indicated possible involvement of fungi in mungbean soil sickness. Nemacur, however, had no effect probably because the 4-mo interval between crops reduced the nematode populations to an insignificant level. These results indicate that soil sickness is complex and is not caused by a single group of organisms.

Fertilizer application, as expected, did not correct the growth inhibitory effects caused by continuous cropping (Table 22).

Table 21. Pesticidal treatments in continuously cropped plots. IRRI, 1982 dry season.

Pesticidal treatment	Dosage	Primary target organisms
Chloropicrin	116.7 liters/ha	All organisms
Benomyl (50% ai)	20.0 kg ai/ha	*Rhizoctonia* and *Fusarium*
Validacin (0.03% ai)	2.0 kg ai/ha	*Rhizoctonia* only
K-salt of hydroxy-isoxazol solution (41.52% ai)	3 ml solution/m²	*Corticium*
Nemacur (50% ai)	20.0 kg ai/ha	Nematodes (esp. *Rotylenchulus* and *Meloidogyne*)

Other treatments: Mungbean seed inoculation with *Rhizobium* spp. Fertilizer rate was 20-60-60 kg NPK in mungbean and 100-60-60 kg NPK in dryland rice.

WHAT CAUSES SOIL SICKNESS?

Continuous monoculture in the same field reduced growth and yield of upland rice, mungbean, and cowpea, therefore a one-crop system should be avoided and crop rotation should be encouraged. In a natural ecosystem, the crop specificity of soil sickness is a natural phenomenon that allows other plant species to thrive.

Table 22. Effect of pesticides in reducing growth inhibition due to continuous cropping of upland rice. IRRI, 1982 dry season.[a]

Crop history	Pesticidal treatment	Plant ht (cm)	Grain yield (t/ha)	Yield index[b]
16 continuous rice crops	Chloropicrin	77 a	2.5 a	294
	Benomyl	67 c	1.1 c	136
	Validacin	68 bc	1.5 bc	177
	None	67 c	0.8 cd	100
	None[c]	58 d	0.4 d	54
8 yr continuous fallow	Chloropicrin	77 a	2.5 a	299
	Benomyl	73 ab	2.3 ab	274
	Validacin	70 bc	2.2 ab	260
	None	71 bc	2.4 a	280
	None[c]	58 d	0.8 cd	96

[a]In a column, means followed by a common letter are not significantly different at the 5% level.

[b]$\text{Yield index} = \frac{\text{Grain yield of treatment}}{\text{Grain yield of control}} \times 100.$

control = no pesticide but with fertilizers.

[c]Fertilizers not applied.

Table 23. Effect of pesticides in reducing growth inhibition due to continuous cropping of mungbean. IRRI, 1982 dry season.[a]

Crop history	Pesticidal[b] treatment	Flowering stage		Bean yield (t/ha)
		Plant ht (cm)	Dry wt (g/20 plants)	
21 continuous mungbean crops	Chloropicrin	47 b	215 b	1.2 a
	Benomyl	35 c	121 c	0.8 bcd
	Nemacur	28 d	105 c	0.6 d
	Validacin	29 d	89 c	0.6 cd
	K-salt of hydroxy-isoxazol	35 c	102 c	0.7 bcd
	None	27 d	92 c	0.6 d
19 continuous sorghum crops	Chloropicrin	67 a	231 ab	0.9 abc
	Benomyl	66 a	250 ab	1.1 a
	Nemacur	69 a	264 ab	1.1 a
	Validacin	69 a	222 ab	1.1 a
	K-salt of hydroxy-isoxazol	66 a	270 a	0.9 ab
	None	64 a	239 ab	1.1 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]All treatments applied with 20-60-60 kg NPK/ha.

Results of this study indicate that fungi and nematodes are not the direct cause of soil sickness and that interactions of various organisms are involved. Continuous monoculture changed the composition of the biological soil components and the proliferation and activity of soil and rhizosphere microflora (Borner 1960, Barclay and Crosse 1974, Vancura et al 1977). Biological soil sickness obviously does not depend on a single group of microorganisms, and not all microorganisms responsible for soil sickness directly affect plants (Vlasta et al 1982).

Some researchers (McCalla and Haskins 1964, Nishio Kusano 1976, Mulder 1974) found that an association between root exudates and microorganisms caused the growth inhibitory effects and, therefore, the crop specificity of soil sickness.

Growth reduction in upland rice appears to differ from that in lowland rice (Table 10). The effect of phytotoxins caused by decomposing organic matter on lowland rice was reported by Chou et al (1977) and Cannel and Lynch (1984).

Fungi and nematodes have been studied as causes of soil sickness of upland rice and mungbean, but bacteria have not been considered. In a related study on apple replanting problems, however, Vlasta et al (1982) found no direct involvement of bacteria in soil sickness.

Interactions of pathogenic agents probably are involved. Adding benomyl and thiram (Table 15) cured soil sickness despite the presence of potential pathogenic nematodes, which suggests a possible interaction of nematodes and fungi. Nematodes in healthy soil did not damage mungbean (Table 15), which suggests the presence of *antinematode* activity of soil. Continuous cropping may not only increase the population of potentially pathogenic organisms that are not singly pathogenic, but may also cause them to be pathogenic in combination with other weak pathogens. Continuous cropping also decreases the antagonistic effects of soil flora on weak pathogens. Soil sickness problems cannot be answered by a simple application of Koch's principle.

Chemical soil sterilization is an effective, but expensive, means of alleviating soil sickness in upland rice and mungbean. Soil sickness in annual crops can be agronomically controlled by a rotation scheme with an unrelated crop. The inclusion of resistant crops such as sorghum is suggested. Having at least one fallow season is another remedial measure, but soil sickness re-occurs if the same crop is planted twice in 1 yr.

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