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Formulated Soil Amendment for Controlling Fusarium Wilt and Other Soilborne Diseases

In Taiwan, plant diseases caused by species of *Fusarium*, reported as early as 1919 by Sawada (10), now number more than 20. The most frequent species is *F. oxysporum* Schlecht. (Table 1), and the most serious disease is Panama wilt of banana caused by a new race (race 4) of *F. oxysporum* f. sp. *cubense* that attacks the currently grown Cavendish varieties resistant to other races. Other economically important diseases are Fusarium yellows of radish and Fusarium wilt of watermelon, melon, muskmelon, and pea. Fusarium wilt of flax was serious about 10 years ago, but flax cultivation has declined rapidly and the disease is now infrequent. Field conditions greatly affect occurrence of Fusarium wilt of pea, cucumber, bitter gourd, melon, and spinach; disease is usually mild in paddy fields and severe in dryland fields. Fusarium wilt of watermelon is most serious in sandy soils, especially under monoculture conditions. Radish yellows usually occurs in acidic soils in central and northern Taiwan.

Table 1. Important *Fusarium* diseases in Taiwan

Pathogen	Host	Disease	Importance[a]
Fusarium moniliforme	Asparagus	Root rot	+
F. oxysporum f. sp. *apii*	Celery	Wilt	+
f. sp. *asparagi*	Asparagus	Wilt	+
f. sp. *batatas*	Sweet potato	Wilt	+
f. sp. *conglutinans*	Cabbage, mustard	Yellows	+
f. sp. *cubense*	Cavendish banana	Yellows, wilt	+++
f. sp. *cucumberinum*	Cucumber	Wilt	+
f. sp. *lini*	Flax	Wilt	+
f. sp. *lycopersici*	Tomato	Wilt	+
f. sp. *melonis*	Melon, muskmelon	Wilt	++
f. sp. *momordicae*	Bitter gourd	Wilt	++
f. sp. *niveum*	Watermelon	Wilt	++
f. sp. *pisi*	Pea	Wilt	++
f. sp. *raphani*	Radish	Yellows	+++
f. sp. *spinaciae*	Spinach	Wilt	+

[a] +++ = greatest importance.

Formulating a Soil Amendment

Continuous extensive agricultural practice that depends heavily on application of chemical fertilizers has resulted in loss of organic matter, an increase in acidity, and accumulation of toxic elements in fertile soils (1,3), creating an environment favorable for development of certain soilborne diseases. Successful control of soilborne diseases in greenhouse tests by amendment of soil with organic matter is well documented (2). Also, some growers in Australia use organic amendments of soil to control Phytophthora root rot in avocado orchards (2). The general belief, however, is that such practices would not be economically feasible in the field.

Because we found that amending soil with certain organic materials and inorganic fertilizers significantly shortened the survival time of *F. oxysporum* f. sp. *niveum* and reduced the incidence of disease (6,7), we initiated a project in 1980 to formulate a soil amendment for controlling Fusarium wilts of various crops in the field. To ensure development of an inexpensive soil amendment, we used wastes from the agriculture, aquaculture, and steel industries as the main sources of organic and inorganic materials. In preliminary tests, we amended soils infested with *F. oxysporum* f. sp. *niveum* with 1% (w/w) each of bagasse, rice husks, cornstalks, cow manure, oyster shell powder, and mineral ash, individually or in various combinations, and determined the population change of the pathogen in each soil after 1 month. The combination of bagasse, rice husks, oyster shell powder, and mineral ash was most effective in reducing the population of the pathogen. Then, to obtain a soil amendment that would not only control the disease but would also enhance plant growth, we added different combinations of fertilizers to the combined bagasse, rice husks, oyster shell powder, and mineral ash. From these tests we formulated a soil amendment that achieved our goals and named it S-H mixture, using the first letters of our surnames. S-H mixture consists of 4.4% bagasse, 8.4% rice husks, 4.25% oyster shell powder, 8.25% urea, 1.04% potassium nitrate, 13.16% calcium superphosphate, and 60.5% mineral ash (31% silicon dioxide, 44% calcium oxide, 1.7% magnesium oxide, 18% aluminum oxide, and 1% ferrous oxide).

Results of Laboratory and Greenhouse Tests

In unamended sandy soil, the population of *F. oxysporum* f. sp. *niveum* decreased 55% in 1 month; in soil amended with 1% (w/w) S-H mixture, the population decreased 92% (11). In unamended soil, 36% of chlamydospores of *F. oxysporum* f. sp. *niveum* germinated; in soil amended with S-H mixture, only 4% germinated. In artificially infested soil, 94% of watermelon plants were infected 38 days after planting; in soil amended with S-H mixture, no plants were infected. Growth of watermelon plants was also greatly enhanced in amended soil (Fig. 1), and root weight and number increased about 28 and 65 times, respectively (Fig. 2).

Results in loam soil were similar. The population of *F. oxysporum* f. sp. *niveum* decreased 30% in 1 month in unamended soil and 80% in amended soil, and 40% of chlamydospores germinated in unamended

Fig. 1. Watermelon plants growing in soil infested with *Fusarium oxysporum* f. sp. *niveum* and (left) amended with 1% S-H mixture and (right) not amended.

soil and 8% germinated in amended soil. In artificially infested soil, 100% of watermelon plants showed Fusarium wilt symptoms in 38 days, compared with 26% of plants in amended soil. S-H mixture also enhanced growth of watermelon plants in loam soil.

Field Trials

Naturally infested fields at four locations (Erhlun, Silo, Taichung, and Pingtung) in southern and central Taiwan were selected for field trials. Half of each 500-m^2 test field was amended with S-H mixture at a rate of 900–1,200 kg/ha; the other half was used as a control. In the Erhlun and Silo fields, which contained about 600 propagules of *F. oxysporum* f. sp. *niveum* per gram of soil, S-H mixture controlled 76 and 84% of Fusarium wilt of watermelon, respectively (Table 2). In the Taichung and Pingtung fields, which contained 1,200–3,400 propagules of the pathogen per gram of soil, S-H mixture controlled 61 and 57% of the disease, respectively. In each field, watermelon plants growing in amended soil were larger and stronger than those growing in unamended soil (Fig. 3). S-H mixture at a rate of 1,200 kg/ha cost about $158/ha and increased the value of the yield from the Pingtung field by about $749/ha at the local market price. Thus, application of S-H mixture to control Fusarium wilt of watermelon in the field is not only economically feasible but also profitable.

Radish yellows caused by *F. oxysporum* f. sp. *raphani* is serious in certain areas of Taichung. Application of S-H mixture at a rate of 1,200 kg/ha in a farmer's field reduced the incidence of that disease by 46% and increased yield by 40%, for an equivalent increase in income of about $753/ha (9) (Fig. 4). In a field at Taoyuang infested with *F. oxysporum* f. sp. *conglutinans*, S-H mixture at a rate of 1,200 kg/ha reduced the incidence of mustard cabbage yellows by 34% and increased yield by 53%, representing a profit of about $960/ha.

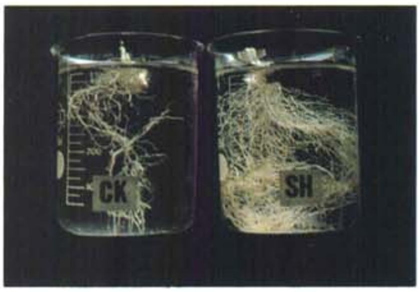

Fig. 2. Roots of watermelon grown in soil not infested with *F. oxysporum* f. sp. *niveum* and (right) amended with 1% S-H mixture and (left) not amended.

Fig. 4. Radish plants growing in field infested with *F. oxysporum* f. sp. *raphani* and with soil (right) amended with S-H mixture at a rate of 1,200 kg/ha and (left) not amended.

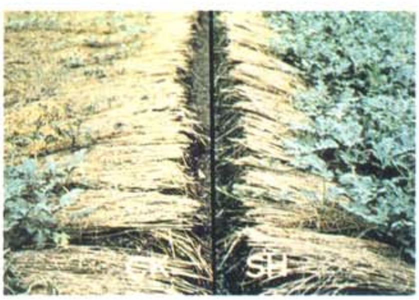

Fig. 3. Watermelon plants growing in field infested with *F. oxysporum* f. sp. *niveum* and with soil (right) amended with S-H mixture at a rate of 1,200 kg/ha and (left) not amended.

Fig. 5. Clubroot of Chinese cabbage, caused by *Plasmodiophora brassicae*, controlled by amending soil with S-H mixture (minus urea) at a rate of 1,200 kg/ha; soil in plot at center rear not amended. (Courtesy W. H. Hsieh)

Table 2. Control of Fusarium wilt of watermelon by soil amendment with S-H mixture in the field

Locality	Soil type	Treatment	Disease[w] (%)	Average length of vines[x] (cm)
Erhlun	Sand	None	7.8 a[y]	173
		S-H mixture	1.9 b	340
Silo	Loamy fine sand	None	2.5 a	ND[z]
		S-H mixture	0.4 b	ND
Taichung	Loam	None	81.5 a	142
		S-H mixture	32.1 b	299
Pingtung	Fine sandy loam	None	46.7 a	168
		S-H mixture	20.1 b	189

[w] Recorded 60–75 days after planting.
[x] Average of 10 plants measured 45 days after planting.
[y] Data followed by the same letter at each location are not significantly different ($P = 0.05$) according to Student's t test.
[z] ND = not determined.

Mechanisms of Disease Control by Amendment with S-H Mixture

When applied to soils, S-H mixture inhibited spore germination and enhanced germ tube lysis of both *F. oxysporum* f. sp. *niveum* and *F. oxysporum* f. sp. *raphani* (12). The mixture inhibits spore germination of both fungi in nutrient solution, indicating nonbiological factors may play an important role in suppressing pathogens in soil amended with S-H mixture. Spore germination of *F. oxysporum* f. sp. *raphani* was reduced in soil amended with mineral ash, oyster shell powder, rice husks, or urea but not in soil amended with potassium nitrate, calcium superphosphate, or bagasse. Mineral ash and oyster shell were the only components of S-H mixture that strongly enhanced germ tube lysis of that fungus in soil, whereas mineral ash was the only component capable of enhancing germ tube lysis of *F. oxysporum* f. sp. *niveum* in soil. Among the major components of mineral ash, only calcium oxide (calcium chloride) and ferrous oxide (ferric chloride) significantly reduced spore germination of *F. oxysporum* f. sp. *raphani* and only ferrous oxide (ferric chloride) enhanced germ tube lysis of *F. oxysporum* f. sp. *niveum* in soil. Oyster shell is rich in calcium and chitin; possibly, the calcium component directly inhibits germination and the chitin component indirectly enhances germ tube lysis through stimulating growth of chitinolytic microorganisms, especially actinomycetes in soil.

S-H mixture is alkaline and therefore tends to increase soil pH. Because soils with high pH values are unfavorable to development of radish yellows and Fusarium wilt of watermelon, an increase in pH may contribute to disease suppression, although to what extent is not known.

Microbial activity was associated with suppression of wilt pathogens in soil amended with S-H mixture. Populations of fungi and actinomycetes increased 25 and two times, respectively, in amended soil (12). The mixture did not affect the population of soil bacteria, however. When microbial inhibitors such as streptomycin, rose bengal, and pentachloronitrobenzene (PCNB) were added to amended soil, pathogen germination increased.

Results of our study suggest that a multitude of factors probably are involved in suppressing Fusarium wilt diseases in soil amended with S-H mixture. The mixture may suppress the pathogen directly with its inorganic components and indirectly (by enhancing microbial activity) with its organic and inorganic components. The mixture is very high in calcium, and calcium reportedly increases host resistance to Fusarium wilt diseases. S-H mixture also stimulates growth of plant roots, which in turn may reduce the damage caused by the pathogen.

Expansion of the Project

After our field trials demonstrated the feasibility of using S-H mixture to control Fusarium wilts, we and other plant pathologists tested the mixture on different soilborne diseases. Clubroot of cruciferous plants caused by *Plasmodiophora brassicae* Wor., first found in Taiwan in 1933 by Sawada, has become a serious disease in central and northern Taiwan in recent years (10). In greenhouse tests, about 35% of Chinese cabbage plants growing in artificially infested soil had severely clubbed roots. The percentage of affected plants was reduced to 1.4% by amending the soil with 0.5% S-H mixture (minus urea) and to 0% by using 1% S-H mixture (4,14). In a field test, S-H mixture applied at a rate of 1,200 kg/ha resulted in 66% control of clubroot of Chinese cabbage and a 57.6% increase in yield, equivalent to a profit of about $1,061/ha (Fig. 5).

Cucumber blight caused by *Phytophthora melonis* Katsura has become prevalent recently throughout Taiwan, especially during the summer. Amending the soil with S-H mixture at a rate of 600 kg/ha combined with spraying the upper parts of cucumber plants with metalaxyl (Ridomil) provided excellent control of the disease in a field test. S-H mixture alone was not effective, however, because

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Table 3. Control of soilborne plant diseases by amendment of soil with S-H mixture in the field

Crop	Disease name (pathogen)	Disease (%)		Yield increase with S-H mixture	Comments
		Unamended	Amended	(%)	
Chinese cabbage	Clubroot (*Plasmodiophora brassicae*)	35.0	1.4	57.6	S-H mixture minus urea (4,14)
Cucumber	Phytophthora blight (*Phytophthora melonis*)	100.0	5.0	...	S-H mixture combined with metalaxyl (Ridomil) spray (8)
Pepper	Southern blight (*Sclerotium rolfsii*)	11.7	0.56	36.0	...
Bean	Rhizoctonia blight (*Rhizoctonia solani*)	14.5	1.20	54.0	...
Rice	Sheath blight (*Rhizoctonia solani*)	62.4	19.6	22.0	...
Tomato	Bacterial wilt (*Pseudomonas solanacearum*)	78.0	0	...	Greenhouse test (5,13)

Fig. 6. Bacterial wilt of tomato, caused by *Pseudomonas solanacearum*, controlled by amending soil with 0.5% S-H mixture; (right) amended soil, (left and center) unamended soil. (Courtesy S. T. Hsu)

Fig. 7. Rhizoctonia blight of bean, caused by *Rhizoctonia solani*, controlled by amending soil with S-H mixture at a rate of 900 kg/ha; (left) amended soil, (right) unamended soil.

of aerial infection by zoospores of the pathogen (8).

Bacterial wilt of tomato caused by *Pseudomonas solanacearum* E. F. Smith is one of the factors limiting production of tomatoes in Taiwan. In greenhouse tests, amending the soil with 1% S-H mixture reduced the population of *P. solanacearum* by 99.96% in 6 days. A 0.5% mixture controlled 78% of the disease (5,13) (Fig. 6).

Our field tests also showed that S-H mixture reduced the incidence of Rhizoctonia blight of bean (Fig. 7) and sheath blight of rice caused by *Rhizoctonia solani* Kühn and southern blight of pep-

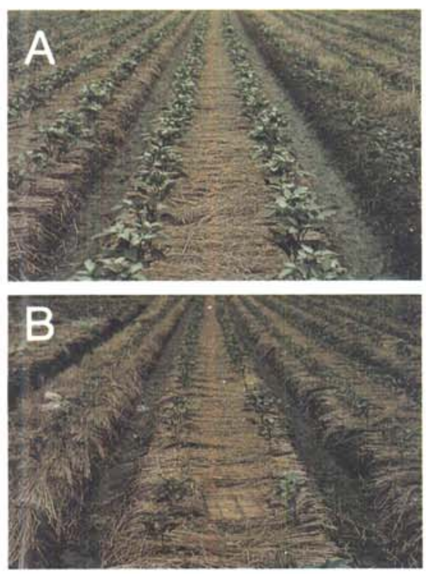

Fig. 8. Southern blight of pepper, caused by *Sclerotium rolfsii*, controlled by amending soil with S-H mixture at a rate of 900 kg/ha; (A) amended soil, (B) unamended soil.

per caused by *Sclerotium rolfsii* Sacc. (Fig. 8). Yield increases due to amending the soil with S-H mixture ranged from 22 to 54% (Table 3).

In 1984, the Patent Office in Taiwan granted us a patent for S-H mixture. Because of the great interest expressed by growers, a fertilizer manufacturer recently contracted to mass-produce S-H mixture for commercial use.

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