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 Panaman 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.

### 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. *nivorum* 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. *nivorum* 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, 3.16% 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. *nivorum* 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. *nivorum* 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. *nivorum* decreased 30% in 1 month in unamended soil and 80% in amended soil, and 40% of chlamydospores germinated in unamended soil.
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 (Erhlin, Silo, Taichung, and Pingtung) in southern and central Taiwan were selected for field trials. Half of each 500-m² test field was amended with S-H mixture at a rate of 1,200 kg/ha and (left) not amended.

**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. *raphanii* (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. *raphanii* 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. *raphanii* 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

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

<table>
<thead>
<tr>
<th>Locality</th>
<th>Soil type</th>
<th>Treatment</th>
<th>Disease (%)</th>
<th>Average length of vines (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erhlin</td>
<td>Sand</td>
<td>None</td>
<td>7.8 a</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-H mixture</td>
<td>1.9 b</td>
<td>340</td>
</tr>
<tr>
<td>Silo</td>
<td>Loamy fine sand</td>
<td>None</td>
<td>2.5 a</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-H mixture</td>
<td>0.4 b</td>
<td>ND</td>
</tr>
<tr>
<td>Taichung</td>
<td>Loam</td>
<td>None</td>
<td>81.5 a</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-H mixture</td>
<td>32.1 b</td>
<td>299</td>
</tr>
<tr>
<td>Pingtung</td>
<td>Fine sandy loam</td>
<td>None</td>
<td>46.7 a</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-H mixture</td>
<td>20.1 b</td>
<td>189</td>
</tr>
</tbody>
</table>

*a* Recorded 60–75 days after planting.

*b* Average of 10 plants measured 45 days after planting.

*Data followed by the same letter at each location are not significantly different (P = 0.05) according to Student's t test.

*ND = not determined.
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 Plasmopera 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 $7.6% 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
Table 3. Control of soilborne plant diseases by amendment of soil with S-H mixture in the field

<table>
<thead>
<tr>
<th>Crop</th>
<th>Disease name (pathogen)</th>
<th>Disease (%)</th>
<th>Yield increase with S-H mixture (%)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unamended</td>
<td>Amended</td>
<td></td>
</tr>
<tr>
<td>Chinese cabbage</td>
<td>Clubroot <em>(Plasmodiophora brassicae)</em></td>
<td>35.0</td>
<td>1.4</td>
<td>57.6</td>
</tr>
<tr>
<td>Cucumber</td>
<td>Phytophthora blight <em>(Phytophthora melonis)</em></td>
<td>100.0</td>
<td>5.0</td>
<td>...</td>
</tr>
<tr>
<td>Pepper</td>
<td>Southern blight <em>(Sclerotium rolfsii)</em></td>
<td>11.7</td>
<td>0.56</td>
<td>36.0</td>
</tr>
<tr>
<td>Bean</td>
<td>Rhizoctonia blight <em>(Rhizoctonia solani)</em></td>
<td>14.5</td>
<td>1.20</td>
<td>54.0</td>
</tr>
<tr>
<td>Rice</td>
<td>Sheath blight <em>(Rhizoctonia solani)</em></td>
<td>62.4</td>
<td>19.6</td>
<td>22.0</td>
</tr>
<tr>
<td>Tomato</td>
<td>Bacterial wilt <em>(Pseudomonas solanacearum)</em></td>
<td>78.0</td>
<td>0</td>
<td>...</td>
</tr>
</tbody>
</table>

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.

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 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.

Acknowledgments

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Literature Cited


