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# THE EFFECT OF SOLARIZATION, METAM SODIUM, BIOLOGICAL SOIL TREATMENTS AND COVER CROP AMENDMENTS ON PINK ROOT INCIDENCE AND YIELDS OF SWEET ONION IN MAUI, HAWAII

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*Abstract.* **Pink root, *Phoma terrestris* E. M. Hans, is among the major limiting factors for the production of sweet onions on Maui, Hawaii, where continuous monocultures are typical. Alternative multi-tactic disease management strategies are needed to promote the sustainability of the sweet onion industry in the production region of Kula, Maui. An experiment was thus conducted to evaluate the effect and interaction of several management strategies on pink root incidence and onion yields. The experiment had a split-split plot design with 4 replications per treatment. The 3 main treatments were a rotation with cabbage, solarization, and a fallow period. The sub-treatments included fumigated and non-fumigated Metam sodium plots. The 4 sub-sub-plots were 'Sordan 79' sudangrass, 'Dwarf essex' rape biomass amendments, an EM1 (Ecoyo Inc.) biological inoculant, and a control. Each plot consisted of a 50 ft bed with 4 rows per bed. The study thus had a total of 96 plots (3 × 2 × 4 treatments × 4 replications). At harvest, 100 bulbs per plot were individually graded and weighed. Disease severity was determined at harvest by a visual root damage index. Results showed significant 2- and 3-way interactions involving the solarization, fumigation, and cover crop treatments. In general, solarization, cabbage rotation, and sudangrass or rape incorporation had positive synergistic effects with fumigation, resulting in greater yields and less disease. The only variables that reduced pink root incidence and increased the number of disease-free bulbs were fumigation and solarization. Overall, the treatment combination with the lowest disease rating was solarization-fumigation-rape biomass incorporation. The highest yields were, in turn, obtained with the solarization-fumigation-biological treatment combination.**

Pink root, *Phoma terrestris,* is among the major limiting factors for the production of sweet onions on Maui, Hawaii. Few control options are currently available for pink root management in onions. General recommendations for control in Hawaii (Hamasaki et al., 1999) include rotation with non-hosts (Tims, 1944; Schwartz, 1995), the use of resistant or tolerant cultivars (Thornton and Mohan, 1996), to minimize plant exposure to stress (Schwartz and Mohan, 1995; Hoffman, 1996) soil solarization (Katen, 1980; Hartz, 1989, Thornton et al., 1995; Pages and Notteghem, 1996), and soil fumigation with products such as Metham sodium (Vapam®, Busan®) and Chloropicrin (Telone C-17®). The use of several control strategies is more likely to be more effective in pink root suppression than any one single strategy. For example, in Australia and Texas, studies showed that the use of soil fumigants in conjunction with soil solarization was more effective than using either individually (Hartz et al., 1989; Porter et al., 1989). However, in Hawaii, none of the practices listed below have been formally evaluated for their effectiveness to manage pink root incidence, under the soils and high elevation conditions where onions are grown in Maui. Thus an on-farm factorial experiment was conducted to evaluate the effectiveness of several combined management strategies, including solarization, metam sodium fumigation, rotation with cabbage, a biological inoculant, and cover crop amendments, to minimize incidence of pink root in onions in Kula, Maui.

## Materials and Methods

The experiment was conducted in a farm on the Kula district of Maui, at 1200 ft above sea level, in a field under onion monoculture for several years and with a history of severe pink root disease incidence. Prior to experiment initiation, to assure uniform pink root infestationduring the experiment and to minimize incidence of other soil-borne diseases, the field plot was fumigated with Telone C-17 and then inoculated with soil known to have a high incidence of pink root disease. The experiment had a split-split plot design with four replications per treatments. The 3 main treatments (2-3 month duration each) were a rotation with cabbage, solarization, and a fallow period. The sub-treatments included fumigated (211 kg/Ha)

Table 1. Sequence of events followed to evaluate the effect of several alternative management practices to control pink root in sweet onions grown in the Kula district of Maui, Hawaii.

| | |
|---|---|
| Sept.-Dec. 1997 | Plant corn to increase disease pressure in the experimental field plot. |
| Jan.-April 1998 | Plant onion to increase disease pressure in field plot. |
| Aug.-Dec. 1998 | Plant onion to increase disease pressure in field plot. |
| March 1999 | Fumigate field plot with Telone C-17. |
| March 1999 | Incorporate pink root & fusarium infested soil in field plot. |
| March 1999 | Plant onion to increase disease pressure in field plot. |
| May 1999 | Transplant rotation crop (cabbage), grow for 7 weeks. |
| July 1999 | Harvest cabbage crop. |
| July 1999 | Incorporate green manure treatments of rape and Sudan grass. |
| May to Aug 1999 | Fumigation with Vapam and solarization with clear plastic mulch. |
| Aug. 1999 | Plant onion transplants and conduct field experiment. |
| Aug./Nov. 1999 | Data collection and disease assessment. |
| Oct./Nov. 1999 | Harvest data collection, disease incidence, and severity assessments. |

and non-fumigated Metam sodium (Vapam®) plots. The 4 sub-sub-plots were 'Sordan 79' sudangrass, 'Dwarf essex' rape biomass amendments, an EM1 (Ecoyo, Inc.) biological inoculant, and a control. Each plot consisted of a 50 ft bed with 4 rows per bed. On each row, 105 two-month old seedlings were transplanted for a total of 1,890 seedlings per treatment plot. The study thus had a total of 96 plots (3 × 2 × 4 treatments × 4 replications) that included all treatment combinations. Main plots were separated from each other by 4 buffer rows (approx. 4.25 ft). The sequence of events followed for the different treatments used is listed in Table 1.

*Main plot treatments.* The rotation crop (cabbage) was transplanted with one-month old 'Tastie' cabbage seedlings and maintained for a period of approximately 2 months until maturity using standard grower practices. The cabbage crop was then harvested and the crop residues field disked and rotovated prior to field preparation for initiation of the main plot treatments. Metham sodium was then incorporated as a chemigant through the drip irrigation system.

*Sub-plot treatments.* Soil solarization was conducted with a 30 mm thick, clear, low density polyethylene plastic (CT Film, Consolidated Thermoplastics Company, Marietta, GA). The experimental area was first rotovated, irrigated, and the plots were then covered with the clear mulch for a period of 3 months.

*Sub-sub plot treatments.* The three amendment treatments included the incorporation of two green manure treatments (sudangrass 'Sordan 79' and rapeseed 'Dwarf essex') and the commercial liquid inoculant EM1 (Ecoyo, Inc.) The green manure crops were seeded in a separate field, adjacent to the experimental plots, and incorporated in August 1999 into the plot area at 10,000 lbs./acre for 'Sordan 79' and 2,000 lbs./acre for 'Humus'. The green manure treatments were incorporated into their designated plots 2 weeks prior to onion planting. The liquid inoculant was sprinkled over the plot area with a watering can at 2 gallons per acre rate prior to onion planting and after planting at 4 consecutive bi-weekly intervals at a 1 gallon per acre rate. The crop was fertilized and drip irrigated following standard grower practices. At harvest, 100 bulbs per plot were lifted and windrowed to allow for field curing. After field curing of the onion, bulbs were evaluated for yield and grade. Disease severity was determined at harvest, by a visual root damage index. To do this, 100 mature bulbs were pulled randomly and rated individually for disease severity on a scale where 0 = no symptoms, 1 = 1-25% of roots infected, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% infection.

Data were subjected to the SAS GLM procedure, and means were separated by Duncan's new multiple range test. Data were transformed as necessary using square root transformations for small numbers and arcsine transformations for percentage numbers. Results shown are from non-transformed data.

## Results and Discussion

Rotation with cabbage and solarization resulted in numerically greater mean bulb weights than the fallow treatment (Table 2). The mean bulb weights for rotation and solarization were 12.2% and 9.1%, respectively, greater than the fallow treatment. A statistical significance was not found between these treatments, however, perhaps due to significant 2- and 3-way interactions found between treatments. The solarization and fallow treatments had a significantly lower disease incidence per bulb, and more disease-free bulbs than the cabbage rotation treatment (Table 2). Previous work with cabbage residues have also found conflicting results with respect to their ability to suppress soilborne diseases (Gamliel and Stapleton, 1993; Chellemi et al., 1997b; Lodha et al., 1997; Coelho and Chellemi, 1999). Overall, Vapam fumigation resulted in heavier bulbs (by 30.5%), more disease-free bulbs (by 19%) and in lower disease levels per bulb (by 16%), than non-fumigated plots (Table 3). The results with vapam are in accordance with previous work in which fumigants effectively reduced soilborne diseases in onion (Hartz et al., 1989; Porter et al., 1989; Pages and Notteghem, 1996), and in other crops (Chellemi et al., 1994; Chellemi et al., 1997a; Ben-Yephet et al., 1998).

Concerning the sub-sub plots, the biological inoculant treatment resulted in significantly heavier bulbs than the green manure amendments and the control (Table 4). How-

Table 2. The Effect of cabbage rotation, solarization, and fallow treatments on the bulb weight, number of disease-free bulbs, and on pink root disease incidence of onion grown in Kula, Hawaii.

| Treatment | Mean bulb weight[z] (g) | Disease-free bulbs (No.) | Pink root incidence (%) |
|---|---|---|---|
| Cabbage Rotation | 216.0 (49.3) a | 614 | 24.7 a |
| Solarization | 210.1 (52.3) a | 789 | 19.2 b |
| Fallow | 192.5 (58.0) a | 735 | 19.2 b |

[z]Coefficient of variation is indicated in parentheses. Numbers followed by the same letter within a column are statistically equivalent according to Duncan's New multiple range test ($P < 0.05$).

Table 3. The effect of vapam fumigation and non-fumigated plots on the mean bulb weight of onion grown in Kula, Hawaii.

| Treatment | Mean bulb weight[z] (g) | Disease-free bulbs (No.) | Pink root incidence (%) |
|---|---|---|---|
| Vapam | 233.5 (47.2) a | 1162 | 19.6 a |
| Control | 178.9 (59.2) b | 976 | 23.3 b |

[z]Coefficient of variation is indicated in parentheses. Numbers followed by the same letter within a column are statistically similar according to Duncan's New multiple range test ($P < 0.05$).

Table 4. The effect of biological inoculant, rape, and sudan grass biomass incorporation treatments on the mean bulb weight and pink root disease incidence of onion grown in Kula, Hawaii.

| Treatment | Mean bulb weight[z] (g) | Disease-free bulbs (No.) | Pink root incidence (%) |
|---|---|---|---|
| Biological inoculant | 222.8 (50.0) a | 519 | 22.4 a |
| Rape amendment | 212.6 (49.5) b | 537 | 21.2 a |
| Sudan Grass amendment | 197.2 (54.7) c | 536 | 22.7 a |
| Control | 192.5 (58.5) c | 546 | 20.5 a |

[z]Coefficient of variation is indicated in parentheses. Numbers followed by the same letter within a column are statistically similar according to Duncan's New multiple range test ($P < 0.05$).

ever, all of these treatments had similar disease levels and the controls actually had a trend toward more disease-free bulbs than the other treatments. Thus the biological inoculant apparently helped to improve onion growth independent of its effect on disease suppression (Table 4). Similarly the rape biomass amendment resulted in heavier bulbs but did not help to reduce pink root incidence.

Because significant 2- and 3-way interactions were found involving the solarization, fumigation, and cover crop treatments, the 24 treatment combinations had to be analyzed separately (Tables 5 and 6). A tabulation of the 3-way treatment combinations that resulted in the greatest number of disease-free bulbs indicate that the top combinations involved vapam fumigation (found in 8 of the top 10 treatment combinations), as well as solarization (5 out of 10) (Table 5). These data are in accordance with results observed in other work, indicating that fumigation was a primary factor responsible for disease suppression when compared to solarization and other management tactics (Hartz et al., 1989; Porter et al., 1989; Chellemi et al., 1994; Chellemi et al., 1997b; Ben-Yephet et al., 1998). However, solarization, cabbage rotation, and incorporation of sudan grass or rape biomass did show a positive synergistic effect with Vapam fumigation resulting in greater onion marketable yields and in a lower disease incidence (Table 6) than the use of vapam alone (Table 2).Overall, the treatment combination with the lowest disease levels was solarization, Vapam fumigation, and rape biomass incorporation which had 14.4% of

Table 5. Evaluation of the combined effect of several treatment combinations on the number of plants (by number and percentage) affected by pink root disease in bulb onion grown in Kula, Hawaii. As indicated in the last column the total number of plants evaluated for each treatment combination is 200 (N = 200).

| Treatment[z] | N-0[y] (no.) | wt-0[x] (gr.) | N-1 (no.) | wt-1 (gr.) | N-2 (no.) | wt-2 (gr.) | N-3 (no.) | wt-3 (gr.) | N-0 (%) | N1&2 (%) | N2&3 (%) | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar-v-rape | 121.0 | 244.8 | 52.0 | 233.2 | 18.0 | 221.8 | 9.0 | 210.4 | 60.5 | 86.5 | 13.5 | 200.0 |
| Solar-v-sudan | 113.0 | 258.9 | 55.0 | 231.2 | 27.0 | 230.8 | 5.0 | 204.8 | 56.5 | 84.0 | 16.0 | 200.0 |
| Solar-v-biological | 112.0 | 269.6 | 52.0 | 271.5 | 23.0 | 297.8 | 13.0 | 270.3 | 56.0 | 82.0 | 18.0 | 200.0 |
| Solar-v-none | 110.0 | 233.8 | 62.0 | 234.0 | 18.0 | 264.4 | 10.0 | 246.8 | 55.0 | 86.0 | 14.0 | 200.0 |
| Fallow-v-sudan | 108.0 | 221.3 | 53.0 | 236.6 | 28.0 | 209.1 | 11.0 | 317.3 | 54.0 | 80.5 | 19.5 | 200.0 |
| Fallow-none-none | 107.0 | 128.7 | 63.0 | 143.5 | 22.0 | 155.0 | 8.0 | 161.5 | 53.5 | 85.0 | 15.0 | 200.0 |
| Solar-none-rape | 99.0 | 197.5 | 53.0 | 190.7 | 33.0 | 148.6 | 15.0 | 172.8 | 49.5 | 76.0 | 24.0 | 200.0 |
| Fallow-v-biological | 96.0 | 261.3 | 59.0 | 252.8 | 22.0 | 236.5 | 23.0 | 239.6 | 48.0 | 77.5 | 22.5 | 200.0 |
| Fallow-v-none | 92.0 | 197.6 | 62.0 | 206.4 | 28.0 | 204.3 | 18.0 | 231.4 | 46.0 | 77.0 | 23.0 | 200.0 |
| Fallow-v-rape | 90.0 | 228.8 | 77.0 | 227.8 | 26.0 | 231.7 | 11.0 | 249.3 | 44.1 | 81.9 | 18.1 | 204.0 |
| Cabbage-v-rape | 87.0 | 229.3 | 56.0 | 212.0 | 39.0 | 218.4 | 18.0 | 214.3 | 43.5 | 71.5 | 28.5 | 200.0 |
| Cabbage-v-biological | 87.0 | 229.5 | 75.0 | 249.7 | 27.0 | 250.7 | 11.0 | 296.4 | 43.5 | 81.0 | 19.0 | 200.0 |
| Fallow-none-biolog | 87.0 | 175.4 | 70.0 | 164.6 | 31.0 | 159.5 | 12.0 | 166.3 | 43.5 | 78.5 | 21.5 | 200.0 |
| Solar-none-none | 85.0 | 151.4 | 77.0 | 147.3 | 26.0 | 139.3 | 12.0 | 120.5 | 42.5 | 81.0 | 19.0 | 200.0 |
| Solar-none-sudan | 83.0 | 157.0 | 74.0 | 143.0 | 26.0 | 134.1 | 17.0 | 143.7 | 41.5 | 78.5 | 21.5 | 200.0 |
| Cabbage-none-sudan | 83.0 | 205.3 | 68.0 | 200.9 | 27.0 | 190.7 | 21.0 | 184.8 | 41.7 | 75.9 | 24.1 | 199.0 |
| Fallow-none-sudan | 78.0 | 164.1 | 74.0 | 136.7 | 30.0 | 171.7 | 18.0 | 132.0 | 39.0 | 76.0 | 24.0 | 200.0 |
| Cabbage-none-none | 77.0 | 197.7 | 68.0 | 217.2 | 29.0 | 222.7 | 26.0 | 232.3 | 38.5 | 72.5 | 27.5 | 200.0 |
| Fallow-none-rape | 77.0 | 158.8 | 79.0 | 176.2 | 31.0 | 163.9 | 13.0 | 140.5 | 38.5 | 78.0 | 22.0 | 200.0 |
| Cabbage-v-none | 75.0 | 210.8 | 79.0 | 214.9 | 33.0 | 231.4 | 13.0 | 223.7 | 37.5 | 77.0 | 23.0 | 200.0 |
| Cabbage-v-sudan | 71.0 | 194.8 | 75.0 | 221.9 | 32.0 | 214.1 | 22.0 | 204.4 | 35.5 | 73.0 | 27.0 | 200.0 |
| Cabbage-none-biolog | 71.0 | 214.0 | 62.0 | 214.7 | 44.0 | 169.6 | 23.0 | 186.7 | 35.5 | 66.5 | 33.5 | 200.0 |
| Solar-none-biological | 66.0 | 189.9 | 76.0 | 202.6 | 30.0 | 226.9 | 28.0 | 171.3 | 33.0 | 71.0 | 29.0 | 200.0 |
| Cabbage-none-rape | 63.0 | 242.7 | 81.0 | 221.0 | 34.0 | 209.2 | 22.0 | 232.8 | 31.5 | 72.0 | 28.0 | 200.0 |

[z]The treatment descriptions are as follows: Solar = solarization, V = vapam fumigation, rape = rape biomass incorporation 2 weeks prior to planting onion, sudan = sudan grass incorporation 2 weeks prior to planting onion, cabbage = 3 month cabbage rotation prior to onion planting, biological = biological inoculation, fallow = 3 month fallow treatment, and none = control.

[y]For each treatment combination bulb number was counted based on the following disease classifications: N-0 = No. of plants with no disease; N-1 = No. of plants with 25% disease incidence; N-2 = No. plants with 26-50% disease incidence; N-3 = No. of plants with over 50% disease incidence. Counts are based on a total possible of 200 bulbs used for disease determinations per treatment, as indicated in the last column.

[x]For each treatment combination the mean bulb weight was calculated for onions following in the following classifications: Wt-0 = Mean bulb weight of plants with no disease; Wt-1 = Mean bulb weight of plants with 25% disease incidence; Wt-2 = Mean bulb weight of plants with 26-50% disease incidence; Wt-3 = Mean bulb weight of plants with over 50% disease incidence.

Table 6. The effect of solarization, Vapam fumigation, biological inoculation, biomass amendments with sudan grass or rape, cabbage rotation, and fallow treatment combinations on the mean bulb weight and percent pink root disease incidence of bulb onion grown in the Kula district, Hawaii (N per treatment combination = 200).

| Treatment combination[z] | Mean bulb weight[y] (g) | Disease incidence[y] (Percent of bulbs showing disease symptoms) |
|---|---|---|
| Solar-V-Biological | 273.40 a | 17.1 g-k |
| Fallow-V-Biological | 253.57 ab | 21.5 b-h |
| Solar-V-Sudan | 246.15 bc | 15.5 jk |
| Cabbage-V-Biological | 243.63 bcd | 20.2 d-i |
| Solar-V-Rape | 238.21 bcde | 14.4 k |
| Solar-V-None | 237.31 bcde | 16.0 ijk |
| Fallow-V-Rape | 229.96 cdef | 19.7 e-j |
| Fallow-V-Sudan | 228.93 cdef | 17.7 f-k |
| Cabbage-None-Rape | 227.12 cdef | 26.9 ab |
| Cabbage-V-Rape | 221.01 defg | 23.5 abcde |
| Cabbage-V-None | 216.66 efgh | 23.0 a-f |
| Cabbage-None-None | 212.47 fgh | 25.5 abcd |
| Cabbage-V-Sudan | 209.10 fgh | 25.6 abcd |
| Fallow-V-None | 204.33 gh | 21.5 b-h |
| Cabbage-None-Biological | 199.75 gh | 27.3 a |
| Cabbage-None-Sudan | 198.86 gh | 25.7 abc |
| Solar-None-Biological | 197.69 h | 27.5 a |
| Solar-None-Rape | 194.01 h | 20.5 c-j |
| Fallow-None-Biological | 168.65 i | 21.0 c-i |
| Fallow-None-Rape | 165.25 i | 22.5 a-g |
| Fallow-None-Sudan | 152.19 ij | 23.5 a-e |
| Solar-None-Sudan | 147.71 ij | 22.1 a-g |
| Solar-None-None | 146.40 ij | 20.6 c-j |
| Fallow-None-None | 137.57 j | 16.4 h-k |

[z]Treatment descriptions are as follows: Solar = solarization, V = vapam fumigation, rape = rape biomass incorporation 2 weeks prior to planting onion, sudan = sudan grass incorporation 2 weeks prior to planting onion, cabbage = 3 month cabbage rotation prior to onion planting, biological = biological inoculation, fallow = 3 month fallow treatment, and none = control.
[y]Numbers followed by the same letter within a column are statistically equivalent according to Duncan's New multiple range test ($P < 0.05$).

the bulbs infected with pink root (Table 6). The greatest yields were obtained with a combination of solarization, fumigation and biological treatment inoculation with a mean weight of 273.4 g per bulb (Table 6). The results obtained in this experiment are supported by the results obtained elsewhere with onion and other crops. These studies indicate that the use of several disease management strategy combinations such as solarization, fumigation, incorporating biomass of green manure crops, rotations, and biological inoculants are more effective when used in combination, as part of an Integrated Pest Management program, than when each control measure is used by itself. The data from this experiment and from work elsewhere also indicate that location-specific environmental factors, and management practices, may determine whether a control practice is successful in one location, but not in another.

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