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Effect of Steam and Solarization Treatments on Pest Control, Strawberry Yield, and Economic Returns Relative to Methyl Bromide Fumigation

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***Abstract*. The phase-out of methyl bromide as a soil fumigant for strawberry (*Fragaria ×ananassa*, Duch.) and increasingly strict regulations of all fumigants suggest that non-fumigant methods of soil disinfestation are needed. In warm climates, solarization controls soilborne pests, but fog and lower summer soil temperatures in coastal California render it unsuitable for pest control relative to chemical fumigation. The first objective of this study was to test the efficacy of steam in controlling soil pests in strawberry production. The second objective was to determine if combining solarization with steam in coastal California would achieve greater pest control and higher yields compared with steam or solarization used alone. The final objective was to determine the economic feasibility of steam and solarization treatments relative to MBPic fumigation. Field studies were conducted at Salinas, CA, in 2007–2008 and in 2008–2009 growing seasons. Treatments included MBPic 67/33% v/v at 392 kg·ha^{-1}, untreated control, solarization, steam, and steam + solarization. For steam + solarization plots, beds were solarized for 2 weeks before and 2 weeks after steam application. Before application of a clear film for solarization, beds were irrigated so the soil moisture was optimal for solarization. Steam was injected into the beds to reach soil temperatures to 70°C or higher up to a depth of 25 cm for 20 min. Soil temperatures during steam and solarization treatments were monitored. Control of soil pests was measured using pathogen and weed propagule bioassays in all treatments. After the 4-week treatment period, 'Albion' strawberry was transplanted in all plots. After transplanting, weed density, weed fresh biomass, and hand weeding time were recorded periodically in each treatment over the cropping season. Weed seed viability in steam and steam + solarization-treated plots was the same or lower than MBPic standard fumigation. Compared with MBPic fumigation, solarization alone was less effective in controlling weeds or reducing the hand-weeding time. Steam and steam + solarization treatments resulted in weed control similar to MBPic fumigation. Only certain steam treatments reduced the number of *Verticillium dahliae* Kleb. microsclerotia similar to the MBPic fumigation at 15-cm depth with no reductions at greater depths. There were no significant differences among treatments in 2007–2008 with regard to yield, but in 2008–2009, yields from steam treatments were comparable to the MBPic-treated plots. Economic analysis performed for the 2008–2009 season showed that net returns from steam or solarization treatments were less than MBPic treatment.**

California accounts for 85% of strawberry (*Fragaria ×ananassa*, Duch.) production in the United States and ≈20% of worldwide production [U.S. Environmental Protection Agency (USEPA), 2009a]. Most of the 16,107 ha under strawberry cultivation in California is in the southern and central counties along the coast, where the climate favors year-round production and harvest [U.S. Department of Agriculture–Economic Research Service (USDA-ERS), 2005, 2010]. High land prices often make it economically difficult to implement crop rotation with strawberry cultivation, resulting in high pest pressures (Duniway, 2002a). Since the 1960s, strawberry producers in California have depended on a mixture of two soil fumigants, methyl bromide (MB), and chloropicrin (Pic) for weed and pathogen control. MB fumigation in strawberry fields has been among the largest uses in California (USDA-ERS, 2000).

MB has been classified as a Class I stratospheric ozone-depleting chemical. Under the Montreal Protocol, the use of MB for fumigation in the United States after 2005 is permitted only through critical use exemption (Anbar et al., 1996; USEPA, 1993). For California strawberries, technically and economically feasible alternatives to MB are needed for control of pathogens such as *Verticillium dahliae*, *Pythium* spp., *Rhizoctonia* spp., and *Phytophthora* spp., root-knot (*Meloidogyne* spp.) and sting nematodes (*Belonolaimus* spp.), and weeds such as nutsedge (*Cyperus* spp.) and winter annuals (USEPA, 2009a). In 2008, a 14% reduction in gross revenue was estimated for California strawberry growers using alternatives vs. those using MB (USEPA, 2009b). Alternative fumigants to MB include Pic, 1,3-dichloropropene (1,3-D), metam sodium, and methyl iodide (Duniway, 2002b). Each of these fumigants has their advantages and disadvantages, and none is a complete replacement for MB (Shaw and Larson, 1999). Besides their inability to provide the spectrum of pest control achieved by MBPic use, these fumigants have to comply with ever increasing regulations. These regulations prohibit the use of fumigants on acreage sufficiently close to "sensitive sites" such as schools and houses, limit application methods and timing, restrict total annual fumigant use, and restrict the use of a specific fumigant in a geographical area, among other restrictions. In addition to direct effects on fumigant use, compliance costs are increasing, reducing growers' net returns.

Solarization is a non-chemical approach widely used in tropical regions to treat infested soils. The potential of solarization for pest control in temperate and subtropical regions, including Arizona, California, Florida, North Carolina, and Texas in the United States, has also been examined, but its efficacy is found to be variable in these regions and not always effective as MB fumigation (Chellemi et al., 1994; Hartz et al., 1993; Ristaino et al., 1991). Solarization may not control all pests and its pest control efficacy is likely to decrease with increasing soil depths (Hartz et al., 1993; Stapleton et al., 2000). Soil solarization is initiated by covering the soil with clear film for a period of 4 to 6 weeks. The best season to practice solarization is summer, which corresponds to the period between May and September in the Central Valley in California and between May/June to August/September in coastal California (Elmore et al., 1997). Pathogens such as *Verticillium* spp., *Rhizoctonia solani*, *Fusarium oxysporum*, and *Sclerotium rolfsii* can be controlled through solarization (Katan, 1984). Solarization controlled