NON-CHEMICAL SOIL DISINFESTATION FOR ORGANIC & SUSTAINABLE VEGETABLE PRODUCTION

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Overview

- Introduction
- Non-chemical methods
  - Solarization
  - Biological/Anaerobic Soil Disinfestation
  - Biofumigation
  - Steam Disinfestation
  - Others
- Conclusions




(Photos: plantsolutionsltd.com, ferraricostruzioni.com, D.M. Butler)

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Background

- Need for non-chemical methods for controlling weeds, ***soilborne*** plant pathogens, and plant-parasitic nematodes in vegetable production systems
  - Global phaseout of methyl bromide (MeBr)
  - Limitations of chemical alternatives to MeBr
  - Organic and transitional systems
  - Agricultural sustainability


(Photos: D.M. Butler)

Background

- Applicability of soil disinfestation to organic systems
  - Transitional periods
  - Fields with high ***soilborne*** plant pathogen, plant-parasitic nematode, or weed infestations
  - Limited rotations due to economics, size, etc.
  - High value crops

(Photo from: organics.tennessee.edu)

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Solarization

- Soil disinfestation via passive solar heating
- Modes of action:
  - Physical mechanisms
    - Direct thermal inactivation
    - Temperatures reduced by cloudiness, low ambient temperatures, and precipitation events
    - Decreasing efficacy with soil depth
    - Soil must have sufficient moisture

(Stapleton, 2000)

Solarization

- Modes of action:
  - Chemical mechanisms
    - Increased nutrient (esp. N) availability
  - Biological mechanisms
    - "Biological vacuum"
    - Beneficial microorganisms typically recolonize soils at faster rates
      - *Bacillus* and *Pseudomonas* spp.
      - *Trichoderma* spp.
      - Free-living nematodes

(Stapleton, 2000)

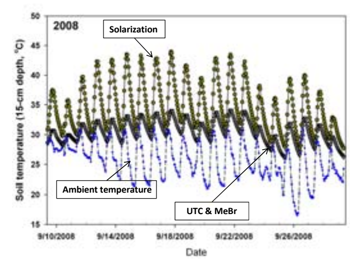
Solarization treatment

- ***Moist*** soil mulched with ***transparent*** polyethylene
- 4 to 6 weeks
- Sunny, warm weather
- Raised-beds or flat applications



Solarization

- Daily maximum temperatures at **15-cm depth**
  - ~45°C (115°F) with solarization
  - < 33°C (~90°F) under reflective silver plastics
- Ambient high ~ 30°C
- Mesophilic soil organisms damage threshold ~39°C



(Butler et al., unpublished)

Solarization limitations

- Plastic cost/disposal
- Paint or cover clear plastic in plasticulture systems
- Limited seasonal usage
  - Length of time out of production
  - Cloudy weather
- Control of certain weeds (esp. nutsedges, other perennials) and plant-parasitic nematodes is variable
  - 45°C will reduce nutsedge emergence, but not lethal (Chase et al. 1999)
- Limited control at greater soil depths

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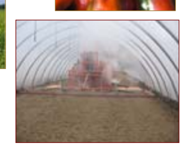


(Photos: plantsolutionsltd.com, ferraricostruzioni.com, D.M. Butler)

Anaerobic soil disinfestation (ASD)

- Anaerobic soil disinfestation (ASD) utilizes methods developed in Japan and the Netherlands
- Also "biological soil disinfestation" or "soil reductive sterilization"
- Widely used in Japanese greenhouses/high tunnels (Shinmura, 2000, 2004; Momma, 2008)
  - Incorporation of easily-decomposible amendments (wheat/rice bran)
  - Flooding the soil
  - Tarping with plastic for ~ 2 weeks
- Researched for open field use in the Netherlands (Blok *et al.*, 2000; Goud *et al.*, 2004)
  - Fresh amendment incorporation (broccoli residues, perennial ryegrass)
  - Irrigation of ~ 5 cm
  - Tarping with plastic for 6 to 15 weeks

ASD

- Effective control of a range of soilborne plant pathogens and plant-parasitic nematodes
  - Soilborne pathogens: *Verticillium dahliae, Fusarium oxysporum* (f. spp. *lycopersici , spinaciae, asparagi & radicis-lycopersici), Fusarium redolens, Phomopsis sclerotioides, Pyrenochaeta lycopersici, Sclerotinia sclerotiorum, Ralstonia solanacearum, Rhizoctonia solani*
  - Nematodes: *Meloidogyne incognita, Pratylenchus fallax*
- Range of crops studied
  - Japan: eggplant, onion, spinach, strawberry, tomato
  - Netherlands: catalpa, maple
  - Argentina: carnation, lettuce, onion
  - Florida: bell pepper, eggplant, tomato
  - California: strawberry

(Blok et al., 2004; Butler et al., 2009 & 2010; Goud et al., 2004; Momma, 2006 & 2008; Shennan et. al, 2009 & 2010; Shinmura, 2002 & 2004; Takeuchi, 2004; Yossen et al., 2004)

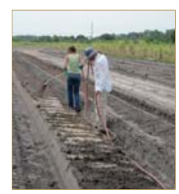
ASD

- Control mechanisms
  - Toxic by-products of anaerobic decomposition
    - Organic acids (e.g. acetic, butyric, propionic)
    - Volatile compounds
  - Biocontrol by anaerobic soil microorganisms
  - Oxygen deficiency
  - Heating by solarization (if applicable)

(Momma, 2008)

ASD Treatment

- Incorporation of (or irrigation with) a labile carbon source
  - Microbial growth & respiration depletes available soil oxygen
  - Microbial community shifts to facultative and obligate anaerobes
  - Incorporation of organic residues can also increase water holding capacity
- Tarping with plastic
  - Limit gas exchange
  - Clear plastic for solarization benefit
- Irrigation to fill porosity
  - Reduce soil oxygen
  - Maintain soil moisture at field capacity
- 3+ weeks treatment period

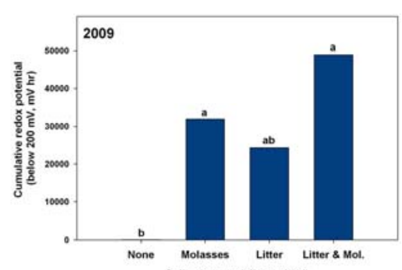


(Photo from: E.N. Rosskopf)

ASD research gaps

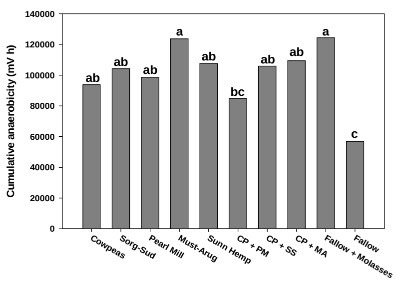
- Limited field-scale research
  - Full crop production cycles
  - Crop yields
  - Impacts on weeds
- Research needed to model and optimize ASD
  - Relationships between anaerobicity and pathogen, nematode & weed survival
  - Effectiveness of C inputs
    - Quality and quantity
    - On-farm vs. off-farm
  - Role of soil microbial community structure
  - Soil fertility/plant nutrition (*organic/transitional systems)
  - Irrigation

Redox potential



(Butler et al., 2010b)

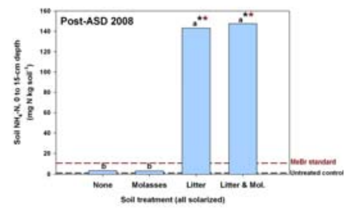
Redox potential



(reprinted from Butler et al., 2010a)

NH_4-N, Post ASD treatment

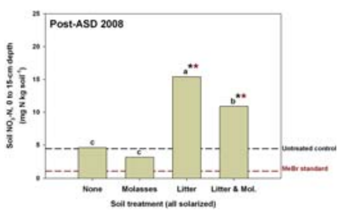
- High NH_4-N accumulation at 0 to 15 cm following ASD treatments with litter



(Butler et al., unpublished)

NO_3-N, Post ASD treatment

- Lower levels of (NO_2+NO_3)-N accumulation at 0 to 15 cm than NH_4-N
- Inhibition of nitrification



(Butler et al., unpublished)

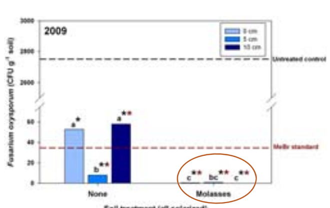
Impact on *P. capsici* inoculum

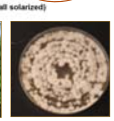
- Control of *P. capsici* equal to that of MeBr for all treatments
- Similar results in greenhouse pot studies
- Concern with ASD and pathogens with water transported spores
  - ASD seems unlikely to increase *P. capsici* incidence, especially at lower levels of initial irrigation coupled with the high level of mortality observed with introduced inoculum

(Butler et al., unpublished)

Impact on *F. oxysporum* inoculum

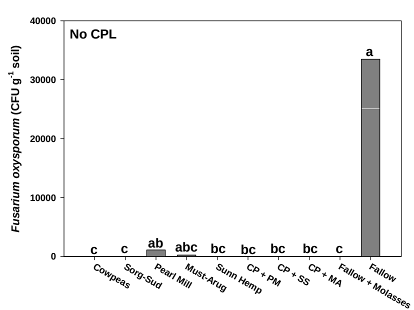
- No impact of applied poultry litter
- Higher mortality of *F. oxysporum* compared to MeBr when molasses applied
- All treatments improved control of *F. oxysporum* compared to UTC





(Butler et al., 2010b)

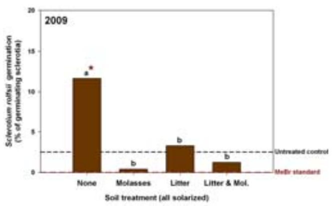
Impact on *F. oxysporum* inoculum



(reprinted from :Butler et al., 2010a)

Impact on *Sclerotium rolfsii* inoculum

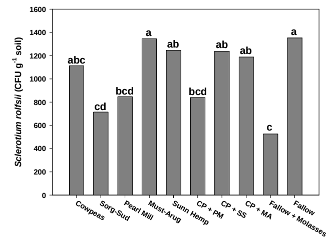
- Germination of introduced *S. rolfsii* sclerotia equal to MeBr for treatments with molasses and/or litter
- Similar results in microplot studies of irrigation rates and litter application
  - 41% germination without applied litter
  - 5% germination with applied litter



(Butler et al., unpublished)

Impact on *Sclerotium rolfsii* inoculum

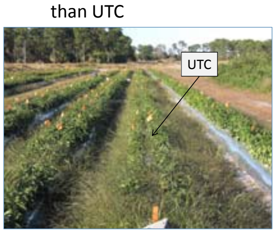
- Less effective control than for *Fusarium*
- Impact of grass amendments (see Stapleton et al., 2010)



(reprinted from: Butler et al., 2010a)

Impact on weeds

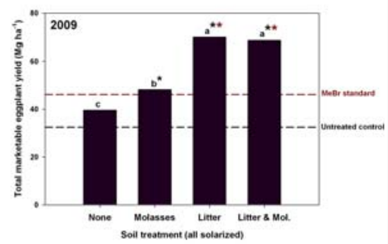
- With 5 or 10 cm initial irrigation, weed control in planting holes (mostly grasses) improved by litter and/or molasses
- All treatments were equal to the MeBr standard and less than UTC



(Butler et al., unpublished)

Impact on eggplant yield (2009)

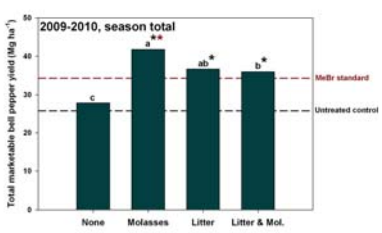
- Few harvest differences (5 harvests)
- All treatments ≥ MeBr standard
  - Treatments with litter exceeded MeBr standard
  - N threshold
  - Improved water relations & nutrient cycling



(Butler et al., unpublished)

Impact on bell pepper yield (2009)

- Solarization alone = UTC
- Litter & litter + molasses = MeBr standard
- Molasses only > MeBr standard



(Butler et al., unpublished)

ASD Summary

- Comparable yields to MeBr standard
- High level of weed control (expecially grasses and broadleaf weeds emerging from planting holes)
- Promising control of plant pathogens and parasitic nematodes
- Methods still being optimized

ASD limitations

- Requires use of plastic
  - But…highly adaptable to plasticulture
- More consistent than solarization, but not as consistent as fumigation
- Nutrients (esp. N) must be well-managed
- Time out of production
- Can produce foul odors
- Technology in need of optimization to local conditions, systems, etc.

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Biofumigation

- Use of green manures and seed meals containing glucosinolates for pest suppression
- Glucosinolates- class of secondary metabolites produced by plants in the order *Capparales,* most notably family *Brassicaceae.*
- Occur in conjunction with enzyme, myrosinase

(Matthiessen and Kirkegaard, 2006)

Biofumigation

- Disruption of plant tissue in moist environment triggers release of degradation byproducts, including isothiocyanate
- Methyl isothiocyanate is the major breakdown product and active fumigant of synthetic soil fumigants metam sodium (Vapam) and metam potassium (K-PAM)

(Matthiessen and Kirkegaard, 2006)

Biofumigation

- Most effective species:
  - *B. juncea* (Indian or brown mustard)
  - *Sinapsis alba* (white mustard)
  - *B. carinata* (Ethiopian mustard)


(Photos: plantsolutionsltd.com)

Biofumigation treatment

- Terminate cover crop at flowering with flail mower
- Incorporate **ASAP**
- Irrigate to provide adequate moisture for hydrolysis
- Plastic may enhance treatment, but not necessary
- Seed meals typically incorporated at a rate of 1 ton acre^{-1}

Biofumigation summary

- Generally good control of soil-borne plant pathogens and plant-parasitic nematodes
- Mustards can be a useful cool-season cover crop
- With cover crop, may be less expensive than other options
- Seed meals also an organic fertilizer (approx. 7-6-3)
- Treatment likely enhanced at higher temperatures


(Photos: plantsolutionsltd.com & wikimedia commons)

Biofumigation limitations

- Seed meals can be very expensive
- Large amount of cover crop biomass needed
  - Moisture
  - Temperature
  - Nutrients (N, S)
- Mustard cover crops can be trickier to manage than other cool-season annuals
- Can be some phytotoxicity
- May be less effective in higher clay content soils
- Typically lower impact on weeds than other options

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Steam disinfestation

- Used for over 100 years in nursery production
- Recent work suggests efficacy at 70°C for 20 min
  (Stapleton et al, 2002)
- Most applicable in high value crops
  - Cut flowers
  - Strawberries
  - High tunnels
  - Orchard replants

(Photo from: E.N. Rosskopf)

Steam disinfestation methods

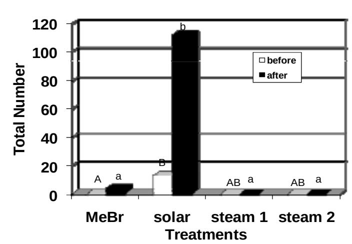
- Tile steaming
- Sheet/sandwich steaming
- Auger steaming



(Leslie et al., 2010; ferraricostruzioni.com)

Steam disinfestation

- Goosegrass control:



(reprinted from Rosskopf et al., 2010)

Steam summary & limitations

- Excellent control of soilborne plant pathogens, plant-parastic nematodes, and weeds
- Widely used in European high-tunnel production
- Limitations
  - Fuel/equipment costs
  - Time requirements
  - Potential soil quality degradation over the long-term
  - Commercial availability of equipment in the U.S.

(Photo from: verdivap.com)

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Other methods

- Non-host, suppressive, or trap crops for plant-parastic nematodes
  - Non-host cash crops (some brassicas, resistant varieties of tomato, bell pepper)
  - Non-host or suppressive cover crops*** (sunn hemp, sorghum-sudan, castor, cowpea, American jointvetch, velvet bean, sesame) (McSorley et al. 1992, 1994, 1999)
  - Trap crops (e.g. arugula, forage radish, white mustard)
- Solar-heated irrigation (Saleh et al., 1989; Chellemi, 2009)
- "Probiotics"?
- Others???

(***highly specific to cover crop cultivar & species of nematode)

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Conclusions

- Soil disinfestation most applicable to:
  - High risk (transitional) periods
  - High infestation fields
  - High tunnels
  - High value crops
- Building good crop rotations, improving soil quality, using best disease management practices likely to be more sustainable in open fields for the long-term

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