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

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

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

Conclusions
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

Solarization treatment

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

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., 2009)
- Limited control at greater soil depths

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Anaerobic soil disinfection (ASD)

- Anaerobic soil disinfection (ASD) utilizes methods developed in Japan and the Netherlands
- Also “biological soil disinfection” or “soil reductive sterilization”
- Widely used in Japanese greenhouses/high tunnels (Shinmura, 2000, 2004; Momma, 2000)
- Incorporation of easily-decomposable amendments (wheat/rice bran)
- Flooding the soil
- Tarping with plastic for ~ 2 weeks
- Research for open field use in the Netherlands (Blok et al., 2000)
- 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 dahlie, Fusarium oxysporum f. sp. lycopersici, Lagenaria, avocado & radish (lycopersici), Fusarium solani, Rhizoctonia solani, Phoma exigua, Sclerotinia sclerotiorum, Rhizoctonia solani
  - Nematodes: Meloidogyne incognita, Pratylenchus fallax
- Range of crops studied
  - Japan: eggplant, onion, spinach, strawberry, tomato
  - Netherlands: celery, tomato
  - Argentina: carnation, lettuce, onion
  - Florida: bell pepper, eggplant, tomato
  - California: strawberry

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)

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

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

- (Blok et al., 2004; Butler et al., 2008 & 2010; Goud et al., 2004; Shinmura, 2001 & 2008; Shennan et al., 2009 & 2010; Takeuchi, 2004; Yossen et al., 2010)
Redox potential

![Graph showing redox potential values for different treatments.]

NH₄⁻N, Post ASD treatment

- High NH₄⁻N accumulation at 0 to 15 cm following ASD treatments with litter

![Graph showing NH₄⁻N accumulation with different treatments.]

NO₃⁻N, Post ASD treatment

- Lower levels of (NO₃⁺NH₄)⁻N accumulation at 0 to 15 cm than NH₄⁻N
- Inhibition of nitrification

![Graph showing NO₃⁻N accumulation with different treatments.]

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

![Graph showing P. capsici inoculum with different treatments.]

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

![Graph showing F. oxysporum inoculum with different treatments.]

Impact on F. oxysporum inoculum (reprinted from Butler et al., 2010a)

![Graph showing F. oxysporum inoculum with different treatments.]

Impact on F. oxysporum inoculum (reprinted from Butler et al., 2010b)

![Graph showing F. oxysporum inoculum with different treatments.]

Impact on F. oxysporum inoculum (reprinted from Butler et al., 2010b)

![Graph showing F. oxysporum inoculum with different treatments.]
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 (especially 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

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)

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

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

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 disinfection

- 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

Steam disinfection methods

- Tile steaming
- Sheet/sandwich steaming
- Auger steaming

Steam disinfection

- Goosegrass control:
Steam summary & limitations

- Excellent control of soilborne plant pathogens, plant-parasitic 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.

Other methods

- Non-host, suppressive, or trap crops for plant-parasitic 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
    - "Probiotics"?
    - Others???

***Highly specific to cover crop cultivar & species of nematode

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

References

- Butler D.M., Kokalis-Burelle N., Muramoto S.T., Sheneman C., Rosskopf D.N. (2010a) Control of soil-borne plant pathogens and plant-parasitic nematodes by anaerobic soil disinfestation (ASD) in raised-bed vegetable production. In internal review, to be submitted to Plant Disease.