Behavioral modification and habitat management tactics for insect suppression: concepts, practice, and limitations

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Outline:

› The Push-Pull Strategy for Pest Management
  - From the research and teaching of my PhD advisor - J.R. Miller (MSU)

› Habitat management for pest control
  - From the research and teaching of D. Landis, Professor (MSU)

› Use of pheromones for pest control
  - From my research and collaboration with S. Lapointe (USDA-ARS)
Push-Pull:

- What is the concept and who came up with it?
- How is it used in pest management?
- What were some of the origins of its use?
- How do you set it up to work in the field?
- What are its strengths?
- What are its limitations?
- Can it be applied in citrus for ACP control?
The **Push-Pull** Tactic was developed considering the “basic principles of insect population suppression.”
Parameters of Damage to Crops:

Damage $\propto D \times A \times S \times T$

- $D$: Density of pest
- $A$: Acceptability of crop
- $S$: Suitability of crop
- $T$: Time of interaction
Parameters of Damage to Crops:

\[ \text{Damage} \propto D \times A \times S \times T \]
Major tactics for managing pests:

- Tolerance
  - Resistance:
    - Mechanical defense
    - Chemical defense
  - Natural enemies
- Removal:
  - Repel
  - Deter
  - Attract
  - Trap
  - Tillage
  - Insecticides
Insecticides

\[ \text{Damage} \propto \text{Density} \times \text{Acceptability} \times \text{Suitability} \times \text{Time of interaction} \]
Resistant Varieties

Damage $\propto$ Density $\times$ Acceptability $\times$ Suitability $\times$ Time of interaction
Behavioral Manipulations:
deterrents, repellents, attractants, anti-feedants

\[ \text{Damage} \propto \text{Density} \times \text{Acceptability} \times \text{Suitability} \times \text{Time of interaction} \]
Behavioral Manipulations:
deterrents, repellents, attractants, anti-feedants

Damage $\propto D_x A_x S_x T$

Effects can vary over time due to shifting behavioral thresholds
Rolling - Fulcrum Model
- Developed by J.R. Miller

Olfaction  Taste  Touch  Vision

E = excitatory  I = inhibitory

EEI  IEI  Rolling Fulcrum  III

Accept  Not Accept
What is the concept of PUSH-PULL?
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It is the simple idea of combining two forces to move something away from where you don’t want it and toward where you do want it.
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It is the simple idea of combining two forces to move something away from where you don’t want it and toward where you do want it.

The idea is that by combining the force of push with the force of pull, the job gets done better than with either force alone. In some cases the effect can be synergistic.
What is the concept of PUSH-PULL?

It is the idea of combining two forces to move something away from where you don’t want it and toward where you do want it.

The idea is that by combining the force of push with the force of pull, the effect on the pest is better than it would be if you used either force alone.
Origins of Push-Pull in pest management—
J.R. Miller’s research on behavioral manipulations of onion fly
Deterrents alone were unsuccessful
Onion fly

Ovipositional Resource Quality

% Maximum Response

Graph showing the relationship between ovipositional resource quality and the percentage maximum response.
The main chemical emitted by onion is: dipropyl disulfide $\text{CH}_3\text{CH}_2\text{CH}_2\text{-S-S-CH}_2\text{CH}_2\text{CH}_3$
Onion fly

- Harris Experiment
- Weston Experiment

% Maximum Response vs. Number of Optimized Factors

- 0 factors: Low response
- 1 factor: Moderate response
- 2 factors: High response
- 3 factors: Very high response
- 4 factors: Maximum response
Cull onions - large onion bulbs; sprouting and not marketable
Seedling Onions (Valued Crop)

Cull Onions (Trap Crop)

Seedling Onions (Valued Crop)
Seedling Onions (Valued Crop)

Deterrents PUSH Fly

Cull Onions (Trap Crop)

Attractants PULL

Seedling Onions (Valued Crop)
STIMULO-DETERRENT DIVERSION: A CONCEPT AND ITS POSSIBLE APPLICATION TO ONION MAGGOT CONTROL

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(Received June 11, 1990; accepted June 30, 1990)

Abstract—Considerable basic information has been gathered on the interaction between the onion fly (Delia antiqua) and its host plant, the onion (Allium cepa). An attempt is underway to manipulate ovipositional behavior of this pest by treating onion seedlings with chemical deterrents while simultaneously providing deeply planted onion culms on which onion flies prefer to deposit eggs. This bipolar strategy of behavioral manipulation, termed “stimulo-deterrant diversion” (SDD), has the advantages of: (1) avoiding severe pest depredation and concomitant overriding of deterrents, (2) combining the effects of “push” and “pull” multiplicatively, and (3) providing opportunities for biological control in sites where the pest becomes concentrated. It is hoped that using SDD along with soil insecticides might make it possible to enhance long-term systemic resistance of D. antiqua to molluscicidal and preservative chemicals used in onion crops.
Dr. Martin Rice working with *Heliothis* moth pests of cotton in Australia independently came up with the push - pull idea simultaneously. Martin and colleagues published a trade article on this approach in the Australian Cotton Grower and a short summary in a *Heliothis* workshop proceedings. He called it the push-pull approach and that name for the tactic became accepted.

Plantings of pigeon-pea served as the PULL  
Neem (azadirachtin) served as the PUSH

Pickett became the champion of the Push-Pull approach
A classic push-pull example
A classic **push-pull** example

Maize Stemborer can destroy up to 80% of the maize crop

Striga -- witch weed parasitic plant that can reduce yields by 20-60%
Stemborers reduced by 30-80%
Witchweed reduced by >50%
Some other examples:

Pickett and coworkers -
several aphid species
  use plant volatiles as repellents
  use other volatiles and pheromones as attractants
pea and bean weevils (Smart et al., 1994)
  use aggregations pheromone enhanced with plant volatiles as pull
use volatiles from repellent plants as the push
Some other examples:

Bark beetles

John Borden and co-workers commencing early 1990s; use aggregation pheromones for the pull and several well-known anti-aggregation chemicals for the push.

Shea and Neustein (1995) saved a stand of rare and highly valuable pines using a variation of the Borden approach.
Example from urban pest:

German cockroach
Nalyanya et al. (2000)

toxic bait
Example from urban pest:

German cockroach
Nalyanya et al. (2000)

**Push-Pull “Corralling”**
Advantages of **Push - Pull**:

- Environmentally friendly
- Is compatible with biological control
- Can have side benefits
- Can spawn new products
  - e.g., Desmodium seed production
- Likely to be sustainable because the forces of selection are not overwhelming
Down-sides of Push - Pull:

- Tends to require considerable work and attention
- Potency of control may not rival insecticides
- Like other behavioral controls, this tactic tends to be quite sensitive to pest density.

Typical insecticides operate quite independently of pest density.
Repellent plants at house eves: *Corymbia, Ocimum* (Push)

Cattle available for alternative blood source (Pull)
Ovi-traps deployed in/around the house (Pull)

Repellent plants deployed around productive larval habitats (Push)
Applications for Citrus

- In India, Garlic plants (which deter many pests) are inter-cropped with citrus
In Asia, citrus is often interplanted with guava.
Effect of Citrus/Guava Interplanting on ACP density

Interplanted and monoculture plots 1 km apart

Lower adult densities

Lower nymph densities

Hall et al. 2008
In Guava-Citrus interplanted orchards, no incidence of HLB

In Citrus monoculture, HLB increases after 5 months

Most monocultures die within 2-3 years

Guava interplants reported to last 15 or more years without HLB

Hall et al. 2008
Guava releases large amounts of sulfur compounds in response to damage

- Dimethyl Disulfide (DMDS) is a known insect repellent
- DMDS is also a known insect neurotoxin

Rouseff et al. 2008
Sulfur compounds repel psyllids in the lab

100 pg/ml of air

Percent psyllid response

Citrus

Citrus With DMDS

Citrus with AMDS

Citrus with DMTS

Citrus with DMDS + DMTS
Treatment of citrus with DMDS

5 replicated 0.4 acre plots of sweet orange cv. ‘Valencia’

Treatments:

1) DMDS-treated plots
2) Untreated control
Application of DMDS can reduce psyllid populations in the field

Mean ± SE number of ACP per 10 trees per replicate

Days after treatment

Significantly different by Student t-test

- Control
- DMDS

200 disperser per acre
3 kg DMDS per acre
Potential application of Push-Pull for Citrus Pest Management:

For Push-Use repellent. Can either use a plant (allium sp. or Guava). Or can possibly use synthetic repellent like sulfur compounds that repel psyllids.

For Pull-Use attractant plant. Perhaps sacrifice a row of citrus that is heavily pruned and fertilized to keep producing new flush that will act as psyllid attractant. Or, alternatively, plant Murraya hedge rows around citrus grove to act as attractant.

One in a while, spray trap-crop attractant with insecticide to kill off psyllids.
Conclusions:

Push-Pull is very common-sense idea

It is still young as a formalized tactic: its full scope remains to be worked out; e.g., nature of possible synergisms between push and pull (additive; multiplicative, other)

It is probably most likely to be adopted and sustained in situations where insecticidal controls are not available.

It is no silver bullet; it probably will operate best in an setting where this tactic is integrated with various other tactics (Killeen et al., 2004).

It’s possible dependency on pest density needs to be understood and respected.
Habitat management—modify habitat to modify insect behavior for pest control

- Disturbance and agricultural landscape structure
- How landscape structure affects natural enemies
- Habitat management to improve biological control
- Thoughts on designing agricultural landscapes
Disturbance

• “Any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment.”

Pickett and White 1985
Crop Landscapes

• Disturbance Regime
  - Frequent
  - Intense
  - Uniform

• Result
  - Uncouples natural enemies and non-host resources
What Beneficial Insects Need

• Food
  - Pollen
  - Nectar

• Shelter
  - Overwintering sites
  - Moderate microclimates
  - Refuge from tillage, pesticides etc.

• Hosts/Prey
  - Primary
  - Alternate
Conservation Biological Control

Manipulation of the environment to enhance the survival, fecundity, longevity, and behavior of natural enemies to increase their effectiveness.

Habitat Management

A subset of conservation biological control methods that alters habitats to improve availability of the resources required by natural enemies for optimal performance.
Habitat Management

“Beetle Banks”

“Sown Weed Strips”
Carabids as Generalist Predators
Manipulating Arthropod Density

Natural density

Reduced density

Augmented density

plot

11.5 m

0.15 m
Pupal Consumption

$R^2 = 0.7026$

Number of Beetles (sqrt transformed)

% Pupae Removed (arcsin trans.)

Four most predominant beetle species: *P. melanarius*, *P. chalcites*, *P. lucublandus*, *P. permundus*

Menalled et al. 1999. BioControl. 43: 441-456
Carabid Refuge Strip Experiment
Carabid Species Richness

Mean Number of Carabids/Trap/Day

* Significant T-test (season-long)

Refuge
Control

Experimental Site

Block I

Refuge strip
Control corn strip

Insecticide treated areas

Block II

15m x 15m plot with plastic barriers

Block III

Block IV

32 m
66 m
Habitat Management

- Know what pests you hope to reduce
- Know what types of natural enemies to favor
- Design habitats to favor specific beneficials
Habitat Management for Beneficials Through the Year

• Winter

• Provide suitable overwintering sites
  - Sheltered locations
  - Plant residue
  - Cover crops
Habitat Management for Beneficials Through the Year

- Spring
  - Early spring green-up
  - Food
  - Shelter
Habitat Management for Beneficials Through the Year

- Summer
  - Diversity of flowering plants
  - Overlap of blooming periods
  - Accessible nectar
Habitat Management for Beneficials Through the Year

- Summer Cont.
  - Alternative hosts/prey
  - Moderated microclimates
Habitat Management for Beneficials Through the Year

- Fall
  - Limit residue burial
  - Plant cover crops
Some Additional Guidelines

• Consider wind and water flow patterns
  - Soil and water retention
• Connectivity
• Closer is better
• A little is better than none at all
• Perennial & annual habitats
• Additional sources of income
  - e.g. timber, nursery stock, cut flowers
• Aesthetic and wildlife considerations
Mating Disruption:

- What is the concept?
- How does it fit into pest management broadly?
- What are the actually mechanisms underlying?
- How have we figured out how it works?
- What’s the future?
- What are its limitations?
Communication among moths

- Females release pheromone from specialized glands
- Straight chain ca. 12-14 carbon alcohols, acetate, aldehydes
- Typically blends of 3-4 compounds
- Antennal sensilla sift pheromone molecules from the air
- Odorant stimulates receptor cells within antenna
What is the “normal” situation?
What is the “normal” situation?

female
What is the “normal” situation?

gentle wind

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female
What is the “normal” situation?

gentle wind

eggs
What is the “normal” situation?

Mating disruption is intended to stop this!!
Mating disruption is intended to stop this!!
Alternative models (explanations) for mating disruption:

1. **Desensitization** - males cannot find calling females because pre-exposure to pheromone causes loss of sensitivity in antennae or brain.
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2. **Camouflage** - males cannot find calling females because of interference from an atmospheric background of pheromone released from dispensers.
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3. False-plume-following (Competition) - males are diverted from orienting to authentic females due to competing attraction to nearby false plumes from pheromone dispensers.
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Commercial disruption formulations:

1) Hand-applied dispensers (ropes)
   Rate: 200-500 / acre
   600-1000 X’s a calling female / unit

2) Aerosol emitters
   Rate: 1-2 / acre
   > 300,000 X’s a calling female / unit

3) Sprayable microencapsulated formulations

Greatly magnified
Development of high-density wax-drop formulation

- Paraffin- or microcrystalline-wax formulation
- Contains 5-10% pheromone by weight
- Formulations are made of 30-40% wax and 50-60% water
- Anti-oxidants and proprietary stabilizers protect pheromone
Progress toward high-performance disruption

Photo courtesy of G. Krawczyk, PSU.
Development of mechanized applicator for high-speed deployment of wax drops
Citrus Leafminer: A living infestation

- Transparent and ovoid-shaped egg of citrus leafminer.
- Pupa of citrus leafminer.
Damage Caused by CLM

- Damage heaviest during flush;
- Direct damage greatest to young trees;
- Reduced photosynthesis, tree growth;
- Mines provide entry for pathogens.
More leaf mines = More Canker

Mean no. of mines per leaf per tree

Mean no. of canker lesions per leaf per tree

Untreated

Treated
Citrus leafminer Pheromone

Female sex pheromone:
30 (Z,Z,E)-7,11,13-hexadecatrienal
10 (Z,Z)-7,11-hexadecadienal
1 (Z)-7-hexadecenal

Photos courtesy of J.M.S. Bento
Typical CLM male catch per week in untreated control
Attract-and-kill for leafminer control
Attract-and-kill for leafminer control

Malex™—Pheromone + insecticide attract & kill formulation

Deployed as 1200 drops per acre of crop

We had to re-formulate to replace permethrin with imidacloprid and change the UV-blockers because EPA would not give registration

New formulation is being tested this summer
Attract-and-kill for leafminer control

Has to be applied every 3-4 weeks to get this type of efficacy
For the control of citrus leafminer, *Phyllocnistis citrella*

0.15% (Z,Z,E)-7,11,13-
Tractor-mounted SPLAT applicator developed by International Fly Masters, Inc. Ft. Pierce, FL and USDA, ARS.
Tractor-mounted SPLAT applicator

**ADVANTAGES**

- SPLAT dollops lofted into canopy with minimum velocity;
- Dollops deposited on underside of leaves for rain & uV protection;
- Capable of applying wax matrix, attract-&-kill and other products;
- >350 acres/day;
- Computer printouts.

**OPTIONS**

- Adjustable application height;
- On-the-fly programmable application rates;
- GPS variable rate application;
- GPS mapping output;
- Electronic eye detects skips, re-plants;
- ATV, UTV, or truck mounts available;
- Independent hand gun for spot applications;
- 2’, 3’, and 4’ fan configurations.
No. male CLM/trap/day (± SEM, n = 13) in untreated plots, 2010, Emerald Grove, St. Lucie County, FL

Male CLM/trap/day

Date, 2010
Trap catch (% of untreated controls)

Dates of application
- 5 April
- 3 June
- 2 August
- 8 October

Dates of application:
- 100 g/acre
- 200 g/acre

Date, 2010
Border effects: Is it possible to reduce product and application costs by incorporating intentional coverage gaps?
Experiment design

Attenuation of trap catch disruption with distance from treated area.

SPLAT-CLM™

untreated

Spacing:
within row: 12.5 ft (3.8 m)
between rows: 25 ft (7.6 m)

Plots
26 rows x 600’ = 8.6 acres (3.5 ha)
4 reps
Attenuation of trap catch disruption with distance from treated area.

**100 g/acre**

\[ y = 3 \times 10^{-6}x^2 - 1 \times 10^{-5}x - 0.082 \]

\[ R^2 = 0.87 \]

**200 g/acre**

\[ y = 3 \times 10^{-6}x^2 - 0.0002x - 0.045 \]

\[ R^2 = 0.91 \]

Trap catch as proportion of untreated control.
80% coverage, 20% gap (50’)

67% coverage, 33% gap (75’)

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<thead>
<tr>
<th>Application Rate</th>
<th>Nominal</th>
<th>Effective</th>
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<tbody>
<tr>
<td>200</td>
<td>160</td>
<td></td>
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<tr>
<td>400</td>
<td>320</td>
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<tr>
<th>Trap catch disruption (%)</th>
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<tr>
<td>25%</td>
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<tr>
<td>50%</td>
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<tr>
<td>75%</td>
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<td>100%</td>
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<table>
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<tr>
<th>Effective rate (g/acre)</th>
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<tr>
<td>3  0  0  0  7  0  0  0</td>
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Nominal rate (g/acre)
- Blue dots: 200
- Red dots: 400
Conclusions

- Advanced mechanical application for SPLAT;

- Initial trap catch disruption following SPLAT-CLM applications >95%;

- Longevity of mechanically-delivered SPLAT-CLM dependent on viscosity;

- Preliminary results and modeling suggest intentional gaps to reduce cost.