# *Landscape managment and insect pest population control in agriculture systems*

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**Landscape managment and insect pest population control in agriculture systems**

Ferreira, CP; Esteva, L; Godoy, WAC; Cônsoli, FL (2014), Landscape diversity influences dispersal and establishment of pest with complex nitritional ecology. Bulletin of Mathematical Biology. DOI 10.1007/s11538-014-9975-1.

Garcia, A; Cônsoli, FL; Godoy, WAC; Ferreira, CP (2014), A mathematical approach to simulate spatio-temporal patterns of an insect-pest, the corn rootworm *Diabrotica speciosa* (Coleoptera: Chrysomelidae) in intercropping systems. Landscape Ecology. DOI 10.1007/s10980-014-0073-4.

# *Objective*

How we can manipulate habitat to control *Diabrotica speciosa* population?

(a) larvae stage

(b) adult stage

The immature and adult stages of this insect exploit different host plants to achieve their best fitness. While the best larval growth and survival is obtained when infesting corn roots (C4 host plants), adult survival and reproduction is best when adults feed on beans and soybean (C3 host plants).

Injury caused by this insect during its life cycle in different crops.

(b) larvae stage.

(a) adult stage.

The development of investigative scenarios and tools that integrate such complex development strategies, in which population ecology is heavily affected by the fitness of two stages of development in different agroecosystems with the landscape structure, is highly desired to study insect management.

# *Biological parameters measures in laboratory*

1. development time and viability of the larvae stage:
    1. potato: 36,5 days and 84,1%;
    2. corn: 25,1 days and 75,9%;
    3. soyabean: 26,9 days and 30,1%;
    4. bean: 27,8 days and 9,4%;
2. adult survival:
    1. potato: after 37 days, 100% for M and 95% for F;
    2. corn: after 17 days, 100% of mortality for M and after 28 days 100% for F;
    3. soyabean: after 37 days, 45% for M and 80% for F;
    4. bean: after 37 days, 80% for M and 90% F;
3. number of eggs:
    1. potato: 577,5 eggs/female;
    2. corn: 10,2 eggs/female;
    3. soyabean: 85,6 eggs/female;
    4. bean: 600,8 eggs/female;
4. development time and viability of the eggs:
    1. 8,8 days and 82,0%

# *Landscape - heterogeneous mosaic formed by interactive portions.*






# *Several techniques...*

We report on the use of a spatial explicit model and clustering analysis in order to investigate habitat manipulation as a strategy to regulate natural population densities of *Diabrotica speciosa*. Habitat manipulation involved four major agricultural plants used as host by this herbivore pest to compose intercropping landscapes. Available biological parameters for *D.speciosa* on bean, soybean, potato and corn obtained under laboratory conditions were used to group the homogeneous landscapes, composed by each host plant, by a similarity measure. We derive the mean-field approximation for this automata model, from which we obtained conditions for insect invasion. Finally, we accomplished a sensitivity analysis to verify which parameter influences more the pest population in the model.

**Cellular automata + Clustering analysis**

# Cellular automata model

We construct a two two-dimensional stochastic cellular automata which are coupled. We assume that there are $p$, with $p = 1, .., M$, different site's habitat type. Each time step corresponds to one day, and the update rules are the following:

CA 1 (immature):

1. an occupied cell has a probability $\mu + \sigma$ to become empty as a result of immature mortality or adult emergence (depend on the resource type);
2. empty cell has a probability $\Psi$ to become occupied as a result of adult oviposition (depend on the resource type);

CA 2 (adult):

1. an occupied cell has a probability $\gamma$ to become empty as a result of adult mortality (depend on the resource type);
2. empty cell has a probability $\sigma/2$ to become occupied as a result of adult emergence.

Adult insect dispersion occurs between each time step, and all direction is equally probable.

# *Mean field limit - one resource*

Neglecting spatial correlations among cells, the immature and adult density at time $t$ is given by:

$$\begin{aligned}
&\theta = 1 - (1 - \phi\rho_2(t))^{25}, \quad \text{and} \\
&\rho_1(t+1) = (1 - \rho_1(t))\theta + \rho_1(t)(1 - \mu - \sigma), \\
&\rho_2(t+1) = \rho_1(t)(1 - \rho_2(t))\frac{\sigma}{2} + \rho_2(t)(1 - \gamma),
\end{aligned} \tag{1}$$

where $\mu^{-1}$ is the immature survive time, $\sigma^{-1}$ is the immature development time, $\gamma^{-1}$ is the adult survive time, and $\phi$ is the adult oviposition rate.

The stationary solutions are given by:

$$\rho_1(t+1) = \rho_1(t) = \rho_1 \quad \text{e} \quad \rho_2(t+1) = \rho_2(t) = \rho_2.$$

Therefore, we have the species extinction $P_1 = (0,0)$ and the species persistence $P_2 = (\rho_1, \rho_2)$ separate by $R_0$, which measure the number of female adult generate by a female adult that belongs to the generation before. This threshold can be obtained by

$$(1-\rho_2\phi)^{25} = \sum_{k=0}^{25} \binom{25}{k} (-\rho_2\phi)^k = 1 - 25\rho_2\phi + ...,$$

taking the first order approximation

$$\begin{aligned} \rho_1(t+1) &= (1-\rho_1(t))25\phi\rho_2 + \rho_1(t)(1-\mu-\sigma), \\ \rho_2(t+1) &= \rho_1(t)(1-\rho_2(t))\frac{\sigma}{2} + \rho_2(t)(1-\gamma), \end{aligned} \tag{2}$$

the stationary solutions given by $P = (\rho_1, \rho_2)$ are:

$$P_1 = (0,0) \quad \text{e} \quad P_2 = (\frac{R_0 - 1}{R_0}, \frac{\sigma}{2\gamma}\frac{R_0 - 1}{R_0}),$$

where $R_0 = \frac{25\sigma\phi}{2\gamma(\sigma+\mu)}$. Therefore,

$$\boxed{\text{if } R_0 < 1 \Rightarrow P_1 = (0,0),}$$

on the other hand

$$\boxed{\text{if } R_0 > 1 \Rightarrow P_2 = (\rho_1, \rho_2).}$$

$R_0$ represents the average number of daughters produced by each female insect over her lifetime, and it is also an estimate of the control efforts necessary to maintain the insect population below the economic injury level.

# Sensitivity analysis

Can be done analytically or numerically, for example:

$$\Delta R_0 = \frac{25}{2\gamma(\sigma + \mu_I)}\Delta\phi \quad \Delta R_0 = -\frac{25\sigma\phi}{2(\sigma + \mu_I)}\frac{1}{\gamma^2}\Delta\gamma.$$

In this case, we have that $\Delta R_0$ varie linearly with $\Delta\phi$ and, the differential with respect to $\Delta\gamma$ shown that $\Delta R_0$ is more sensible for small $\gamma$ values. The negative signal indicates that when $\gamma$ increase ($\Delta\gamma > 0$), $R_0$ decrease ($\Delta R_0 < 0$).

The above results can be easily generalized for landscapes with $M$ resources taking into account the density $\tau_p$ of sites occupied by the resource $p$, $p = 1, ..., M$. For examle,

$$R_0 = \frac{25(\sum_{p=1}^{M}\phi_p\tau_p)(\sum_{p=1}^{M}\sigma_p\tau_p)}{2(\sum_{p=1}^{M}\gamma_p\tau_p)(\sum_{p=1}^{M}(\sigma_p + \mu_p)\tau_p)}, \tag{3}$$

where the contribution of the $p$ resource is weighted by $\tau_p$.

# *Parameters - D. speciosa*

| Resource | Parameters | | | | $R_0$ |
|---|---|---|---|---|---|
| | $\phi$ | $\mu$ | $\sigma$ | $\gamma$ | |
| potato | 0.51 | 0.005 | 0.027 | 0.027 | 199.2 |
| bean | 0.53 | 0.086 | 0.036 | 0.027 | 72.4 |
| corn | 0.012 | 0.011 | 0.04 | 0.036 | 3.3 |
| soybean | 0.076 | 0.045 | 0.037 | 0.027 | 15.9 |

| Agroecological intercropping | $R_0$ |
|---|---|
| 50% potato + 50% corn | 83.4 |
| 30% potato + 70% corn | 50.1 |
| 30% potato + 50% corn+ 20% bean | 64.7 |
| 50% corn + 50% soybean | 10.1 |
| 40% corn + 50% bean | 49.0 |

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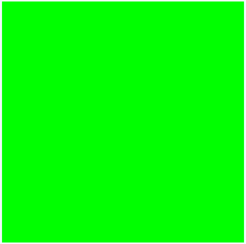
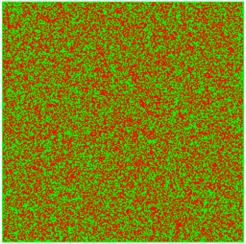
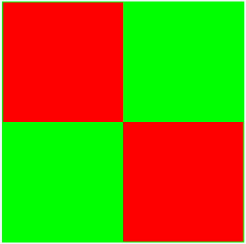
# *Adding spatial structure*



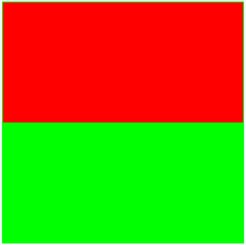
(a) one resource



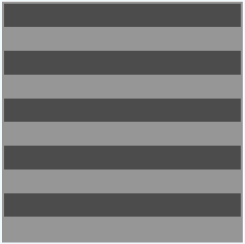
(b) random



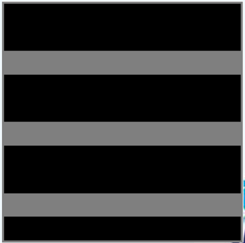
(c) two resource



(d) two resorce



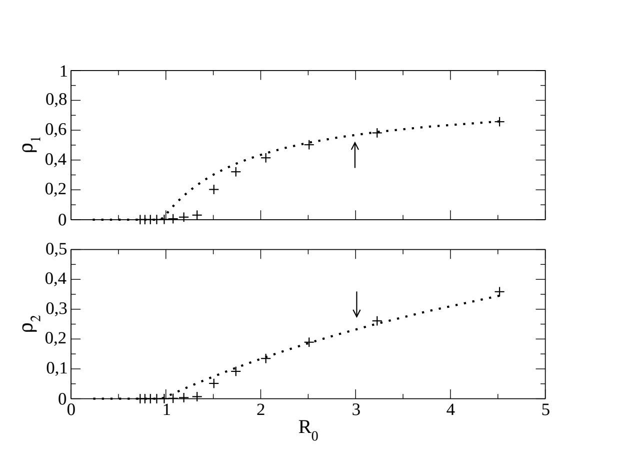
(e) 5:5



(f) 7:3

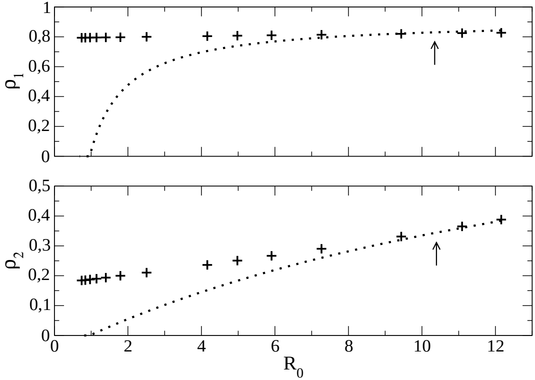
# *Bifurcation diagrams - corn crop*

Results from simulation (+) where the insect are fixed in their positions in a lattice and the MF (...) steady-state for one resource.



# *Intercropping of corn and soyabean*

Results from simulation (+) where the insect are fixed in their positions in a lattice and the MF (...) steady-state for two resource.



# *SLM clustering algorithm*

Given $n$ types of host, the number of different combinations, $k$, that we could accomplish is given by:

$$C_k^n = \binom{n}{k} = \frac{n!}{k!(n-k)!}.$$

Therefore, we used a hierarchical clustering technique to identify similarities between host plants, where similar host were clustered based on the biological parameters.

Now, suppose we have two $p-$dimensional vectors, $\mathbf{x}' = [x_1, x_2 ..., x_p]$ and $\mathbf{y}' = [y_1, y_2, ..., y_p]$. The Canberra distance between these vectors is given by

$$d(\mathbf{x}, \mathbf{y}) = \sum_{i=1}^{p} \frac{|(x_i - y_i)|}{x_i + y_i}, \quad (4)$$

We used a hierarchical agglomerative clustering method, and the single linkage method, which is based on the minimum distance or nearest neighbour. The distance between **xy** and the other element **z** was define as:

$$d(\mathbf{xy}, \mathbf{z}) = min\{d(\mathbf{x}, \mathbf{z}), d(\mathbf{y}, \mathbf{z})\}, \tag{5}$$

where $d(\mathbf{x}, \mathbf{z})$ and $d(\mathbf{y}, \mathbf{z})$ are the distances between elements **x** and **z** and between elements **y** and **z**, respectively.

Example:

$$\begin{aligned} d(P, B) &= \frac{|0.51 - 0.53|}{0.51 + 0.53} + \frac{|0.005 - 0.086|}{0.005 + 0.086} + \frac{|0.027 - 0.036|}{0.027 + 0.036} + \frac{|0.027 - 0.027)|}{0.027 + 0.027} \\ &= 1.051. \end{aligned}$$

# *Dendogram*

(i)

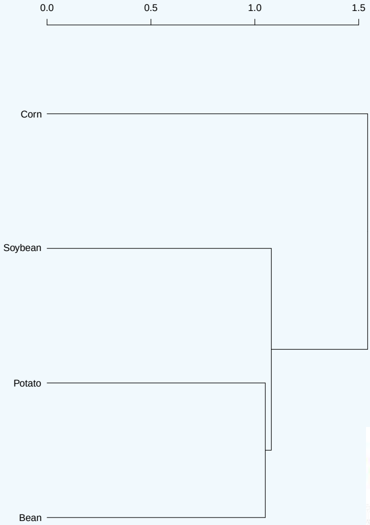
| – | *P* | *B* | *C* | *S* |
|---|---|---|---|---|
| *P* | 0 | | | |
| *B* | 1.051 | 0 | | |
| *C* | 1.668 | 1.926 | 0 | |
| *S* | 1.706 | 1.084 | 1.516 | 0 |

(ii)

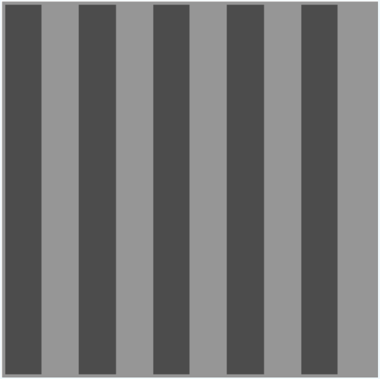
| – | *PB* | *C* | *S* |
|---|---|---|---|
| *PB* | 0 | | |
| *C* | 1.668 | 0 | |
| *S* | 1.084 | 1.516 | 0 |

(iii)

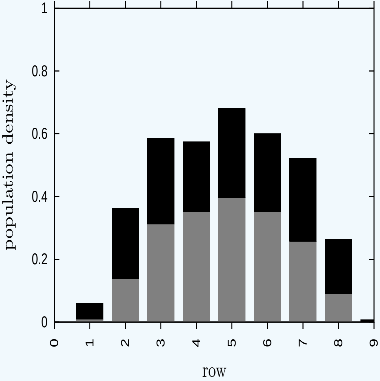
| – | *PBS* | *C* |
|---|---|---|
| *PBS* | 0 | |
| *C* | 1.516 | 0 |



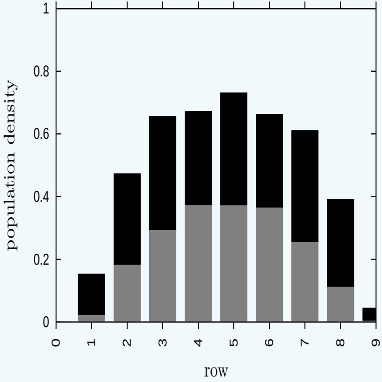
# *Numerical simulations*



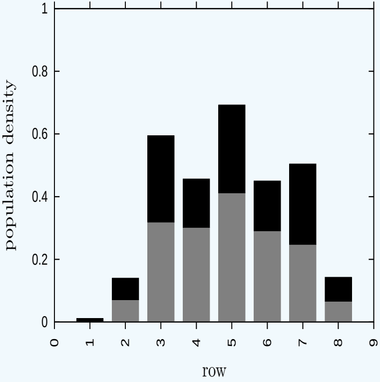
(a) spatial arrangement of the intercropping




(b) potato + soyabean

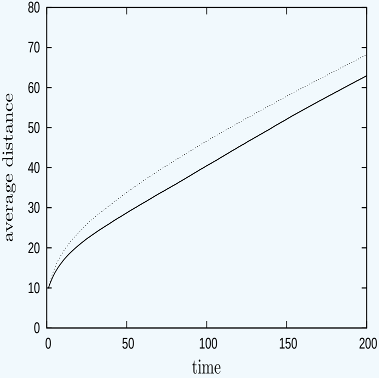



(c) potato + bean

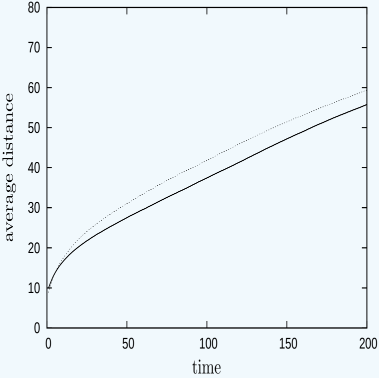



(d) potato + corn

# *Insect diffusion velocity*

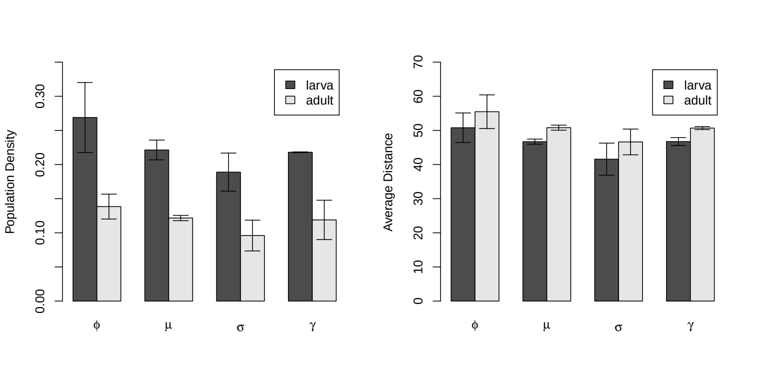



(e) bean + potato



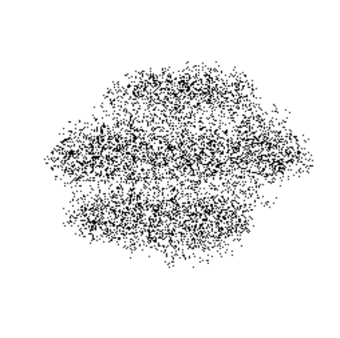

(f) bean + corn

# *Sensitivity analysis*



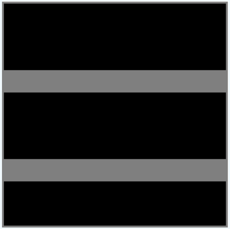
# *Patch shape and boundary contrast*

Snapshot of the lattice configuration showing the immature stage of the pest in different spatial configuration of the agroecological intercropping.

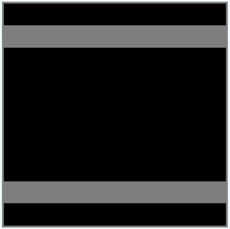


(g) rows

(h) blocks



(i) 8:2



(j) 8:2

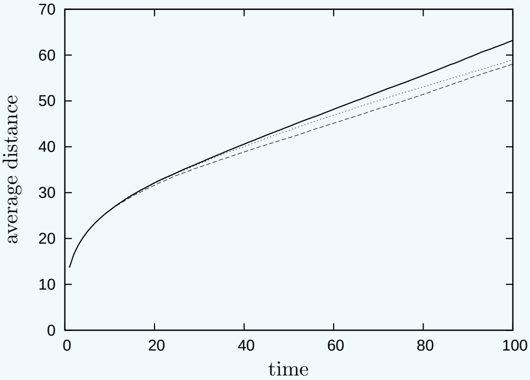



*Figura :* Solid line for homogeneous crop, dotted line for (j), and dashed line for (i).

# *Summarizing*

The MF can overestimate or underestimate the control effort needed to be applied to the insect pest population due to its characteristic of implicit spatial models. However, this approach permits the identification of the relevant parameter that drives population dynamics, and gives population trends.

By combining clustering algorithm results with a CA model, we were able to study the effect of landscape on population growth and spread of the insect pest *D.speciosa*. The results obtained by using this approach showed that the use of corn intercropped with other host plants of *D.speciosa* can severely affect insect dispersion in the field.

Corn can be used as a natural barrier to this pest and the availability of corn at the edged of the field is key for insect population control.

# *Perspectives*

1. mimic insect movement in a more realistic way;
2. include dynamic in the resource;
3. include transgenic crops.

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- Fernando Luis Cônsoli, Depto de Entomolgia e Acarologia, Esalq, USP, Brazil;
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