Modelling neutral agricultural landscapes with tessellation methods: the GENEXP-LANDSITES software - Application to the simulation of gene flow

F. Le Ber, ENGEES-LHYGES & LORIA
C. Lavigne, INRA PSH
K. Adamczyk, INRA MIA
F. Angevin, INRA Eco-Innov
N. Colbach, INRA BGA
J.-F. Mari, LORIA
H. Monod, INRA MIA

Integrative Landscape Modelling, Montpellier, February 3-5 2010

Neutral landscape models (NLM)

NLM (*sensu* Gardner et al., 1987) are much used in ecology. They provide random landscape structures as a baseline

- for comparison with real landscape patterns,
- for an evaluation of landscape structure effects on ecological processes.

NLM model no explicit process giving rise to the landscape pattern, they do model totally random or somewhat constrained covering of the area.

NLM for agronomy and planning ?

NLM in land-use planning or agronomy

Reasons for using such models

- Real data are not always available or are too specific and thus reduce the scope of application of the model results.
- It is necessary to prospect new configurations in order to forecast their effects or to find the best configuration with respect to a given agro-ecological process.
- Neutral landscapes can be used to test the sensitivity of process models to the spatial variability of agricultural landscapes.

NLM developped in ecology are not appropriate for agricultural landscapes:

- agricultural landscapes are mainly geometrical, contrarily to less anthropogenic landscapes
- the field pattern is generally stable and precedes the land-use

Our proposition

A tool for simulating agricultural landscapes, including both their configuration (the field pattern) and their composition (occurrence of categories of land-use)

- produces plot-field segmentations from statistical parameters,
- uses tessellation methods (different geometries)
- allocates land-use to fields (rapeseed, maize, corn, etc.) according to a probabilistic distribution.

The aim is to simulate a large number of landscapes sharing specific properties, in order to study a particular phenomenom and to establish general management rules for these landscapes.

Question :

Which tessellation methods yield geometrical patterns similar to a real landscape with respect to the features that are of importance for the targeted agro-ecological process ?

- Selection of tessellation methods
- Comparison of their spatial characteristics
- Comparison of their effects on the agro-ecological process

Outline

The GENEXP-LANDSITES software: generalities

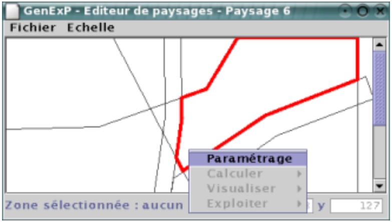
Objectives:
Building farm landscapes with useful characteristics in order to simulate processes of seeds, pollen, or disease diffusion ...
Comparing the characteristics of simulated and real landscapes.
Thus, only 2 dimensions, and the field-pattern is basically considered as a polygonal tessellation.

- Seeds generation: Point processes
- Tessellation methods: Voronoi diagrams; random rectangular tesselation
- Land-use allocation

GenExP-LandSiTes Fonctionalities

Segmentation of the territory (road, zones, etc.), generation of seeds, generation of the field-pattern, post-processing, statistics, file export (raster, vector formats, shapefile).

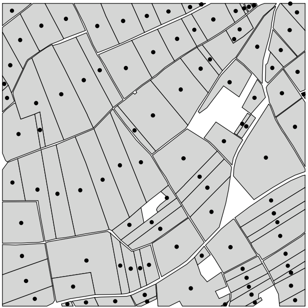
Implementation Java, windows and linux versions.
Gnu Public License.

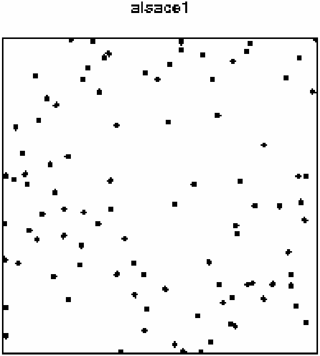


Seeds generation

Classical point processes : uniform point p.

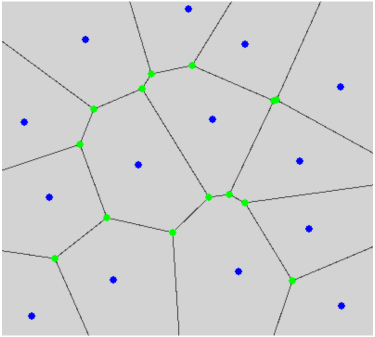
A model of point process for plot centroids: a pairwise interaction process, ie a markov model with distance constraint between points.





Tessellation methods: Voronoi diagrams

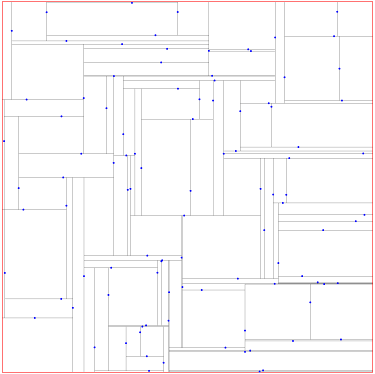
Voronoi diagrams are a covering of the euclidian plan with convex polygons, based on a set E of *seeds*.
Each seed s_1 is associated to a polygon where each point is closer to s_1 than any other seed of E.
The vertices of the polygons are defined by the points located at equal distance of two seeds.



Drawbacks: the polygons are convex, their corner number is high. Advantages: the obvious link between seeds and field-plot centroids.

Tessellation methods: random rectangles

The rectangular tessellation is based on a random set of seeds.
Each seed is randomly associated to a vertical or horizontal direction.
A time 0 a double ray begins growing from each seed following the specified direction at a constant speed. When two rays meet, the longest one stops.

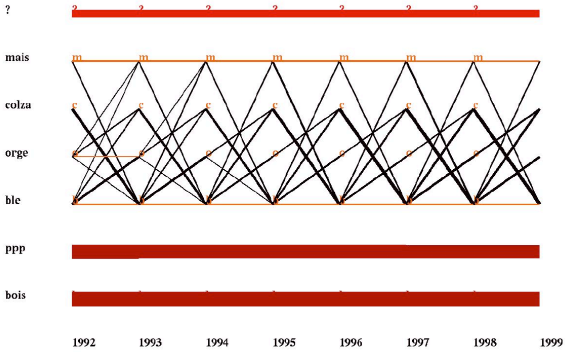


Advantage: this rectangular tessellation is very similar to field-patterns in cash crop or flat regions. Drawback: there is no obvious link between the seeds and outstanding points of real field-patterns.

Allocating crops to fields

the user can allocate crops to the fields according to various methods.

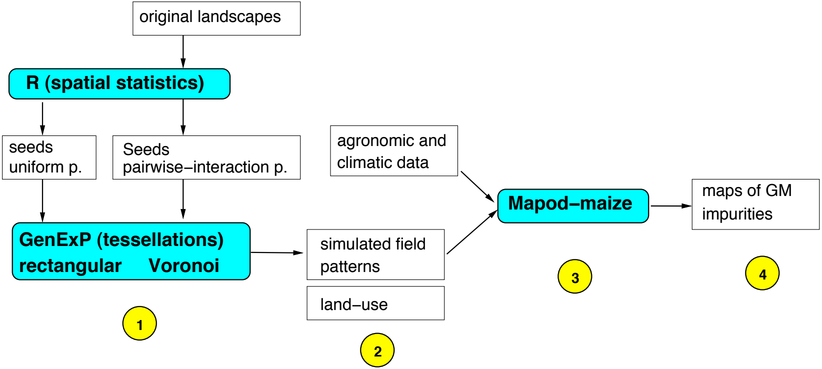
- the land-use mosaic is built randomly according to a distribution of land-uses,
- the land-use mosaic is built according to stochastic rules of crop successions, based on high-order Markov chains. Rules can be extracted from real data thanks to the CARROTAGE system.



Coupling GenExP-LandSiTes with statistical and gene flow softwares

- **R:** The spatial libraries of R provide point processes for the generation of the seeds sets . R contains some descriptors that can be used to characterise the field pattern built by GenExP-LandSiTes.
- Gene Flow Softwares: Mapod-maize (Angevin *et al.*, 2001) simulates gene flow via pollen in a heterogenous space.

Experimentations: the data flow

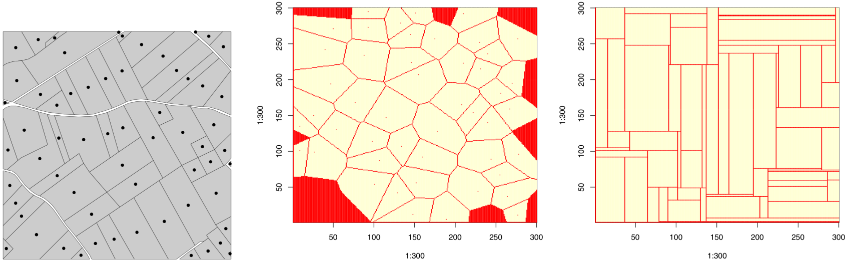


Experimental design

- Generation of field patterns: 3 original patterns (A1, P1, S4) $\times$ 5 seeds simulations $\times$ 2 tessellation methods.
- Crop allocation to fields: 2 proportions of GM maize (10% or 50%) x 3 replicates –the maize proportion was set at 70%
- Pollen dispersal (using MAPOD-maize): agronomic and climatic inputs constant and identical for the GM and the conventional varieties
- GM impurity rates in conventional maize: proportion of seeds containing at least one copy of the transgene at harvest

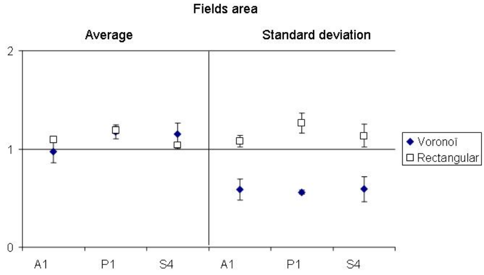
Generation of field patterns

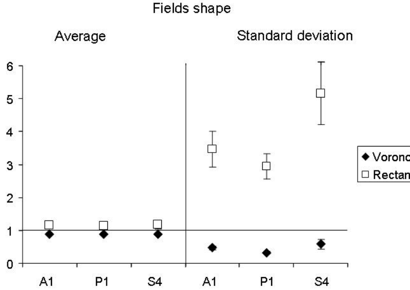
Original pattern S4, Voronoi and rectangular simulations



Statistical analyses: field patterns

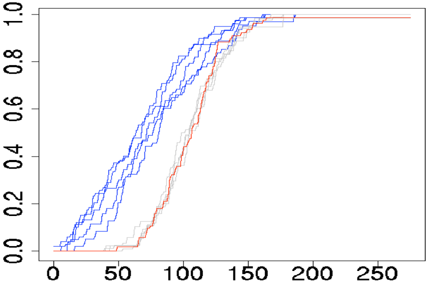
We calculated the number of fields, their area and a shape index ($I_S = \text{perimeter}/4\sqrt{\text{area}}$)





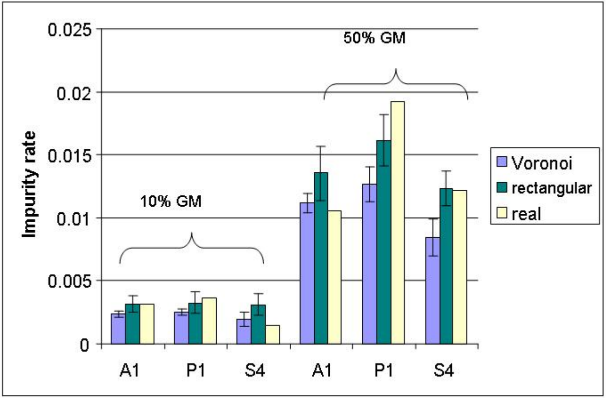
Statistical analyses: distances between centroids

Estimate of the nearest neighbour distance distribution function *G* for the field centroids of pattern A1.

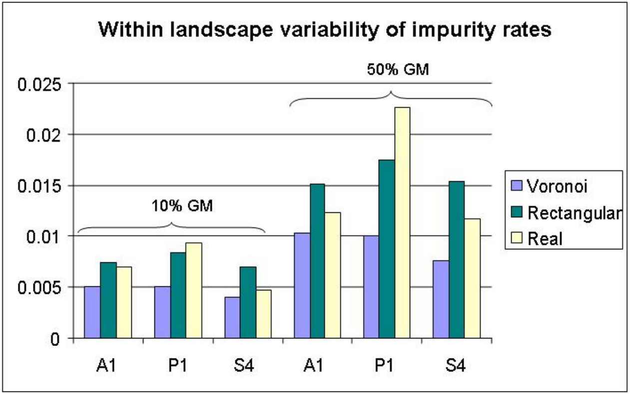


Red line: original pattern.
Gray lines: five Voronoi simulations.
Blue lines: five rectangular simulations.
X-axis: distance (m) between two nearest neighbours.

Statistical analyses: Impact of the tessellation method on GM impurity rates (1)



Statistical analyses: Impact of the tessellation method on GM impurity rates (2)



Simulated field patterns vs original landscapes

For both tessellation,

- good resemblance for the numbers of fields and average field areas
- bad resemblance for the shape and the within-landscape variability of this shape

Voronoi tessellation: compact fields with low variability
Rectangular tessellation: elongated fields with high variability.
The correspondence between the pair polygon/seed and the pair field/centroid proved efficient to simulate patterns where field centroids respect certain constraints

GM impurity rates

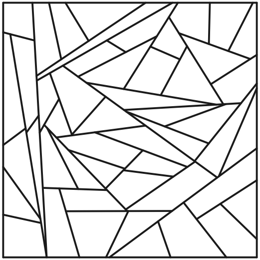
- Voronoi tessellations (large compact recipient fields): GM impurity rates tended to be a little under-estimated
- Rectangular tessellation (elongated field shapes, variability in field area): GM impurity rates tended to be over-estimated

Results on Voronoi tessellations exhibited too low intra-landscape variability

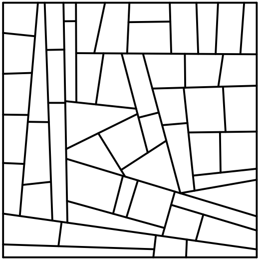
Line-based tessellation model

$\mathcal{T}$: set of planar tessellations with T-vertices :

- probability distribution **P** is given on $\mathcal{T}$; **P** depends on the features of interest up to the set of parameters
- appropriate choice of parameters enables the simulation of landscape-like patterns



$\mathbf{P}(\sum(\text{area})^2)$



$\mathbf{P}(\sum(\text{area})^2, \sum\alpha(\text{vertex}))$

Conclusions and Perspectives

GENEXP-LANDSITES provides neutral farm landscapes (field-patterns and land-use mosaic).
It is based on tessellation algorithms and point processes.

It can be used with various models of agro-ecological processes

Improvements: other tessellation methods, post-processing.

Application for the simulation of agro-ecological processes at the lanscape scale: gene flow, pests,...

GENEXP-LANDSITES is registered at APP (IDDN FR 001 150021 000 S P 2006 000 20700).
It is freely accessible:
`http://www.loria.fr/~jfmari/GenExP/presentation2.html`

Acknowledgments

Original maps were provided by the Institute for the Protection and Security of the Citizen (Joint Research Centre of the European Union) and AUP (Agence Unique de Paiement / French Payment Agency CAP Support). We acknowledge support from the French national program "ACI OGM et environnement" and the INRA-INRIA project PAYOTE.

A few references

- Le Ber F., Lavigne C., Adamczyk K., Angevin F., Colbach N., Mari J.-F. et Monod H., “Neutral modelling of agricultural landscapes by tessellation methods - Application for gene flow simulation”, *Ecological Modelling*, volume 220, pp. 3536-3545, 2009.
- Lavigne C., Klein E. K., Mari J.-F., Le Ber F., Adamczyk K., Monod H., Angevin F., “How do genetically modified (GM) crops contribute to background levels of GM pollen in an agricultural landscape?”, *Journal of Applied Ecology*, 2009.
- Adamczyk K., Angevin F., Colbach N., Lavigne C., Le Ber F. et Mari J.-F., "GenExp, un logiciel simulateur de paysages agricoles pour l’étude de la diffusion de transgènes", *Revue Internationale de Géomatique*, volume 17, numéro 3, 2007.
- Angevin F., Klein E., Choimet C., Meynard J.-M., de Rouw A. et Sohbi Y., “Modélisation des effets des systèmes de culture et du climat sur les pollinisations croisées chez le maïs : le modèle MAPOD”, *In : Rapport du groupe 3 du programme de recherche "Pertinence économique et faisabilité d’une filière sans utilisation d’OGM"*, pp. 21–36, INRA FNSEA, 2001.