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An Agent Based Model for Agro-ecosystem[1]

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Abstract: This paper describes research using an agent-based artificial agro-ecosystem model to simulate the interaction between pest movements and trap crop physical design. The result of simulation shows that artificial agro-ecosystem model has a broad application prospect in the field of agro-ecosystem management.

1. INTRODUCTION

Artificial ecosystems have been defined in the literature [Olson *et al*., 1995] as a system in which a self contained environment is populated by independent entities (agents) representing some level of organization. They are a class of the artificial life model, which is an abstraction of natural living systems, preserving some characteristics of those systems that are the subject of study. The agents in an ecosystem interact locally with each other and with their environments. It has been argued that traditional simulation models are inadequate to implement artificial ecosystems [Ladanyi *et al*., 2003]. They have always some sort of embedded constraints due to the model itself, forcing the system to behave according to the strict rules the model is based upon. An alternative is the use of agents. The rationale behind the modelling through agents [Olson *et al*., 1995] is that each of them implements the level of abstraction necessary to represent an entity while leaving aside aspects considered less important. Agent-based models consist of a collection of individuals, each of which possesses the information needed to behave autonomously, according to a set of rules, and to interact locally with neighboring agents. Interactions are simple and local, yet can lead to complex patterns at the cropland or global scale [Potting *et al*., 2005] [Berec, L., 2002] [Riley, J.R. *et al*., 2002].

Modeling provides an alternative method for studying the interplay between the physical design of trap crop systems and pest population processes. Modeling can be used to reveal patterns produced by the different population dynamics, to provide insight about the importance of the different processes, and to generate testable predictions about pest distribution in different situations. A field-scale testing of trap crop models had been used to limit field experiments to the trap crop designs [Hannunen, S., 2005].

In this paper, we use a modeling approach to get more insight in the mechanisms underlying the efficacy of diversification strategies and to give an indication of the reliability of agro-ecosystem diversification as a pest management strategy. Agent Based Modeling as the technology to implement the model and Swarm as the tool [SDG., 2002].

2. MODEL DESCRIPTION

An artificial agro-ecosystem simulation models consist of three components: a cropland, pests, and a set of behavioral rules. The cropland is typically a two-dimensional grid of cells containing a heterogeneous distribution of crop plant or non-crop plant of interest to the pests. The pests are rational actors that move about on the cropland, interacting with the cropland and other pests. Together, the pests comprise the population to be studied.

2.1 The Cropland

The cropland is a two-dimensional grid with dimensions x*y cropland is distinguished by its (x, y) position with (x, y) as illustrated in Fig.1. The Cropland class encapsulates all states and attributes for an individual cropland grid.

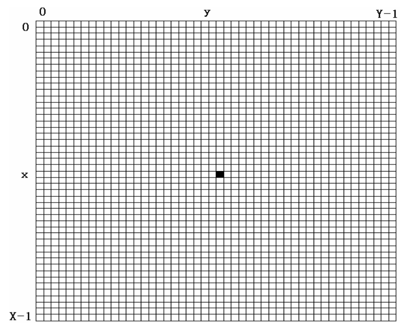

Fig.1 Two-dimensional grid with dimensions x*y.

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Included in this class are member functions for modifying the cell states; also included are functions for retrieving the values of the states and attributes.

2.2 The Pests

The pests are the inhabitants of the cropland. They harvest their “environment” for eats to grow, and die off when their lives go to the end. All pest interactions in the model are purely local. The pests have no global view of the model and cannot interact with any pest or cell on the cropland outside their local neighborhood. They have a number of attributes (with their variable names in brackets):

The efficient accumulated temperature level (levelOfEAT), the current energy level of the pest;

The pest’s life (pestLife), measured in number of running times;

Current position on the cropland (x and y), this information is not available to the pest itself, and is used only by the modeler;

The birthrate of pest (pestBirthRate), set at the start of simulation;

Te density of pest (pestDensity), set at the start of simulation;

The pest’s colour (colour), to be used as a diagnostic tool. This will give the user a view of the state of the population as the model runs.

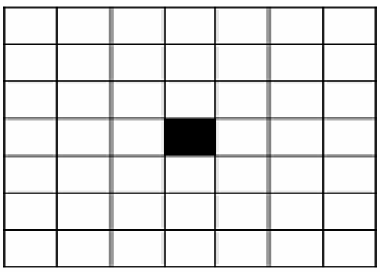

Fig.2 the FOV for a pest if m = 3.

The field of view (FOV) attribute quantifies how far a pest can move from the current (x, y) location as illustrated in Fig.2.

2.3 Movement Rules

At each time step each pest is allowed to move. Population number in trap crop area depends on the movement speed, and the movement speed depends on the pest motility(m). Initial distribution of pests was placed at random at the beginning of simulation. Pest will make a short movement, no further than the neighboring plant, or initiate an emigration from the currently occupied cell. An emigration is initiated when a randomly generated number between 0 and 1 is below the emigration probability of the current position, which is initiated according to the type and state of the plant. The agent movement rule as follows:

*Look at all grids within the FOV.
*Select the closed grid with resource and move to that grid.
*If there is preferable resource in the closed grid, move to it and stay there for a long time.

3. MODEL IMPLEMENTATION

The entire model is implemented using Swarm, and programming in Java. The class capability available in Java naturally lends itself to implementing the artificial agro-ecosystem model. Consequently, we utilize separate class representations for cropland cells, for the entire cropland, for agents, and for maintaining a list of future simulated events.

3.1 The Pests

The PestAgent class encapsulates all states and attributes for a pest agent. In addition to the states and attributes, member functions that implement the pest movement, birth, and death events are included in this class. The basic class structure for a pest agent is as follows:

```
class PestAgent {
    public:     void move();
                void death();
                void birth();
    private:    int FieldOfView;
                int AgentReproEnergy;
                int AgentMetab;
                int AgentAge;
                int AgentMaxLife;
                int AgentReproAge;
}
```

3.2 Implementing the list of events

In the implementation of a next-event simulation model, a suitable data structure is chosen to store the list of future events in simulated time. The simulation engine drives the time evolution of the model by appropriately accessing events in this list. The basic class structure of the event list is as follows:

```
public void PestStep(){
        int pestEnergy = pestInitEnergy;
        ++pestAge;
        if (pestEnergy <= 0 || pestAge>= pestMaxLife){
                pestSpace.putObject$atX$Y(null, x, y);
                modelSwarm.pestDeath(this);
        }
        if (foodSpace.getValueAtX$Y(x, y) !  = 0){
                pestEnergy=pestEnergy+foodCalorie(x, y);
                if(pestEnergy>=pestReproEnergy &&
                pestAge>=pestReproAge &&
                Globals.env.uniformDblRand.
                getDoubleWithMin$withMax(
```

```
                    0.0,1.0<=pestDensity){
            lSwarm.addpests();
            pestEnergy /= 2;
      }
      pestEnergy = pestEnergy - pestMetab;
}
```

The ordering of cropland related events is shown below in table.1.

Table 1. The ordering and Description of the Model Schedules.

Function call	Description	Order
ObserverSwarm._update	Draws cropland and pests	1
ObserverSwarm._updateGraphs	Updates all graphs	2
ProbeDisplayManage.update	Updates all Object Probes	3
Cropspace.updateLattice	Performs Cellular Automata	4
ModelSwarm.death	Removes dead pest	5
ModelSwarm.born	Activates newborn pests	6
AgentStep calls	Runs all Pest routine	7

The model is initialized by placing on cropland a random distribution of agents, each with characteristic attributes and initial states. Consistent with the behavioral rules, as time evolves agents move about the cropland interacting with one another and with the cropland. Statistics are gathered during the model's lifetime to provide data for analyzing the resulting macro-scale behavior of the agents.

4. A CASE STUDY

Simulating experiment had been done on this model to understand the mechanisms underlying pest population response to diversified agro-ecosystems, with a strong emphasis on the behavioral ecology of pests. A case study here is made to model the interaction between pest movements and trap crop physical design in a situation where the pest moves by a random walk with spatially variable mobility.

The configuration of the environment may have an impact on the speed of the redistribution process, and thus it may also influence the efficiency of trap crops. Here, the aim was to define how crop patch size and shape influence pest redistribution from crop to trap crop. The pest moves by a random walk with spatially variable mobility. Situations were considered where fields are composed of rectangular crop patches surrounded by trap crops (Fig. 3), and where the initial density of pest individuals is the same in all parts of the field.

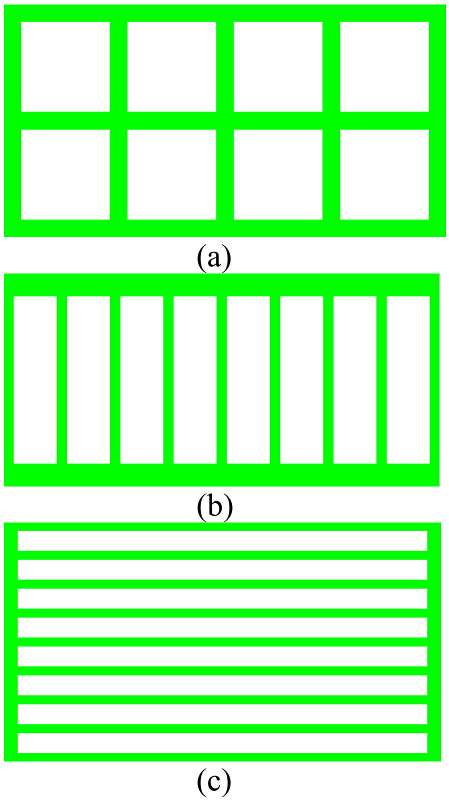

Fig.3 Different designing of trap crop systems in field. All the fields are similar in the total area of the field, the total crop area (white), and the total trap crop area (green). The crop patch dimensions are (a) 50 x 50m^2, (b) 100 x 25m^2, (c) 200 x 12.5m^2.

Parameters in the simulation model as follow：Environment size (Size), Pest type (Species), Mix plant probability (MixPro), Pest density size (PestDen), Max simulate time(MaxTime) (Table. 2). At each time step each pest is allowed to move. The amount of pest population in trap crop area depends on the motility of pests (MotilityOfPest m^2/day), and the motility of pests depends on the FOV of each type of pest as shown in Table. 3.

Table 2. Parameters in the simulation model.

Size	Species	Mix Pro	PestDen	Max Time
250×130	5	5:8	0.02	30

Table 3. The motility of pest and coloration.

Species type	Type1	Type2	Type3	Type4	Type5
MotilityOf Pest	1	2	3	4	5
Coloration	Red	Blue	Yellow	Orange	Purple

Model snapshot is shown in Fig.4. Initial distribution of pests was placed at random at the beginning of simulation (Fig.4a). The most of pests aggregated in the preferred trap crop after 30 days (Fig.4b).

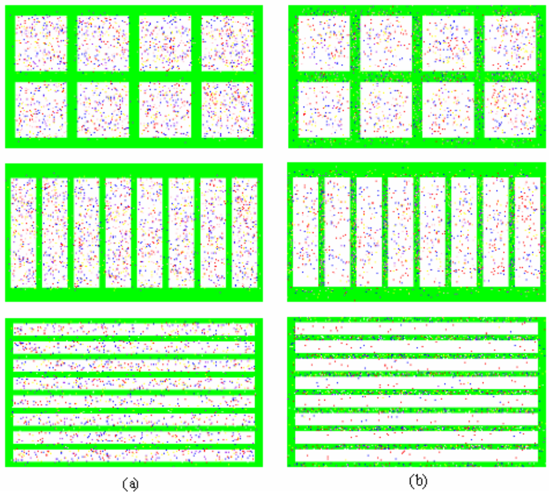

Fig.4. System state graphs showing pests aggregation in the trap crop, (a) time (days) = 1, (b) time (days) = 30.

5. DISCUSSION

Our simulation results show that species-specific mobility is an important factor determining the control efficacy of diversified agro-ecosystems. Fast moving species aggregate more rapidly in the trap crop than slow moving species (Fig. 5). These results demonstrate that the configuration of the environment can have a dramatic impact on the pests' redistribution process, and thus on the efficiency of trap crops. These results suggest that maximizing the perimeter to area ratio of crop patches may be useful if a rapid reduction in pest population is important. Patch perimeter to area ratio can be increased by decreasing patch size or by increasing patch perimeter (i.e. by using elongated instead of square patches) (Fig.3c).

The maximum rates of decay in pest population in the crop for the studied motilities are presented in Fig.6. For example, consider that the aspired reduction in pest population in the crop is 50% in 15 days. If the field is divided into 200×12.5m crop patches, the required reduction in pest density can be achieved using a trap crop only if the motility of pest in the crop is at least $4m^2$/day (Fig.6).

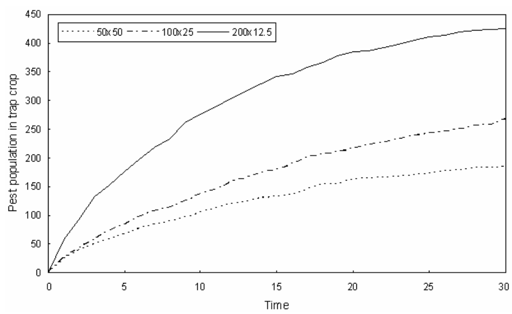

Fig.5. The changing of the pest population emigrating to the trap crop in three different crop patch dimensions. Movement speed was varied by setting the motility (m) per time step.

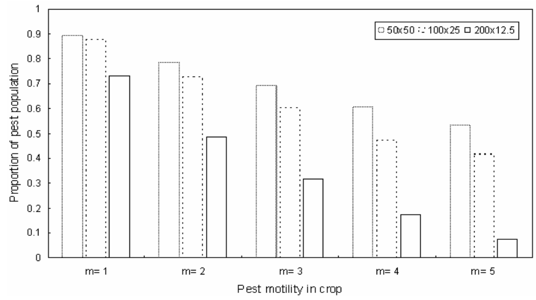

Fig.6. The proportion of the pest population in the crop in three different crop patches at time (day) 15. Pest motility (m) is $1m^2$/day, $2m^2$/day, $3m^2$/day, $4m^2$/day and $5m^2$/day respectively.

For a pest whose motility in the crop is smaller than this, no trap crop can reduce the pest population efficiently enough. If the field is divided into $200\times12.5m^2$ crop patches, a similar reduction in pest population can be achieved only if the motility of pest in the crop is greater than $2m^2$/day. This suggests that, when parameterized with pest motility observed on a crop species, the analytical model could be used to predict the maximum speed of pest redistribution from the crop to the trap crop. Trap crops with such wide variation in pest motilities may have the potential to reduce the pest density in the crop very quickly in others. Thus finding a trap crop that the pest distinctly prefers over the crop appears to be crucial for developing efficient trap crop systems. Designing field layouts to increase the perimeter to area ratio of crop patches may be beneficial.

6. CONCLUSIONS

There are very few studies of population dynamics that systematically vary both behavioral ecological parameters of pest and the composition and spatial arrangement of crop as we have done here. Swarm platform offers distinct advantages for collaborative modeling. The model discussed above has shown that it can be used to simulate the dynamic behavior of certain agro-ecosystem. Object-oriented, agent-based modeling is a powerful and flexible way to bridge the gap between individual behavioral ecology and population dynamics. Thus, these models are perfectly suited to use information from small-scale experiments to identify relevant mechanisms of population dynamics at a field-scale and allow extrapolation to novel conditions, for example to predict the response of pest to agro-ecosystem diversification.

REFERENCES

Berec, L(2002).: Techniques of spatially explicit individual-based models: construction, simulation and mean-field analysis. *Ecol. Model* **150**: 55-81

Hannunen, S(2005).: Modeling the interplay between pest movement and the physical design of trap crop systems. *Agricultural and Forest Entomology* **7**, 11-20

Ladanyi, M., Horvath, L., M. Gael, L. Hufnagel(2003).: An agro-ecological simulation model system. *Applied ecology and environmental research* **1**(1–2): 47-74

Olson, R. L., Sequeira, R. A(1995).: Emergent Computation and the Modeling and Management of Ecological Systems. *Computers and Electronics in Agriculture,* 183-209

Potting, R.P.J., Perry, J.N., Powell, W(2005).: *Pest behavioural ecology and other factors affecting the control efficacy of agro-ecosystem diversification strategies.* Ecological Modeling **182**: 199-216

Riley, J.R., Drake, V.A(2002).: Technologies for pest movement and migration research. Comput. *Electron. Agric* **35**: 57-62

SDG(2002).: Swarm Development Group. Swarm [EB/OL]. Available at: www.swarm.org. September 5