THE PEST CONTROL IN AGRICULTURAL SYSTEMS

Servilia OANCEA[1], I. GROSU[2], A.V. OANCEA[3]

[1] University of Agronomy,
Biophysics Department, Iasi, Romania,
e-mail:lioancea@univagro-iasi.ro
[2]University of Pharmacy and Medicine, Iaşi

[3] "Al.I.Cuza" University Iaşi

The pest control is of great interest in agriculture domain because the pests have been the major factor that reduces the agricultural production in the world. An agricultural ecosystem consists of a dynamic web of relationships among crop plants or trees, herbivores, predators, weeds, etc. Organisms in a cropping system interact in many ways — through competition. There are different approaches in regard the possibility of the modeling of these complex systems. Over the last decade, there has been considerable progress in generalizing the concept of synchronization to include the case of coupled chaotic oscillators especially for biological systems. Many examples of biological synchronization have been documented in the literature, but currently theoretical understanding of the phenomena lags behind experimental studies. From mathematical viewpoint, biological control has been modeled as a two-species interaction. Arneodo et al.(1980) have demonstrated that one can obtain chaotic behavior for the system with three species and Samardzija and Greller(1988) propose a two-predator, one prey generalization of the Lotka-Volterra problem into three dimensions.

In order to formulate the pest control in this work the synchronization of two Lotka–Volterra systems with three species, one prey and two predators is presented. The transient time until synchronization depends on initial conditions of two systems and on the control number. Our results show that the synchronization is about three times faster for all three controllers than for one controller. The synchronization for all species is possible with one controller only if we interfere on predator population. The control method described in this work is very easy and might be useful in the case of the other chaotic systems.

Key words: *biological control, chaos, synchronization, predator*

The pest control is of great interest in agriculture domain because the pests have been the major factor that reduces the agricultural production in the world. Different methods are used in the process of pest management, for instance, chemical pesticides, biological pesticides, computers, atomic energy etc. Of all methods, chemical pesticides seem to be a convenient and efficient one, because they can quickly kill a significant portion of a pest population. But synthetic chemical pesticides introduced and used widely on agricultural crops in order to control the agricultural pests represent a significant food safety risk. Organic agriculture imposed biological control which uses the living organisms to suppress pest populations.

The biological control, due to its environmental and ecological reasons, has been used in every domain of pest management. There are many examples of success using of the biological control, such as the complex of imported parasites, which controls alfalfa weevil which have been applied in greenhouses for control of many vegetables pests. Periodic releases of the parasitoid, *Encarsia formosa*, are used to control greenhouse whitefly, and the predaceous mite, *Phytoseiulus persimilis,* is used for control of the two-spotted spider mite. Generally, there are two kind of method for biological control. In the first method, a small pathogen is introduced in a pest population with expectation that it will generate an epidemic which will persist at an endemic level. For the second one, an insect pathogen is used like biopesticides. There is a vast amount of literatures on the applications of microbial disease to suppress pests. Unfortunately, there are also many cases where effective natural enemies simply have not been found or have not been successfully established in the target area.

An agricultural ecosystem consists of a dynamic web of relationships among crop plants or trees, herbivores, predators, disease organisms, weeds, etc. Organisms in a cropping system interact in many ways — through competition. These organisms constantly evolve and respond to each other, creating a diverse, complex, and ever-changing environment. There are different approaches in regard the possibility of the modeling of these complex systems. One of the famous examples of simple model is logistic map which can model the complex dynamics of some real population system. The Lotka–Volterra model is widely used to study the dynamics of interacting species. The Lotka-Volterra equations are a system of equations proposed to provide a simplified model of two-species predator/prey population dynamics. Although Lotka's and Volterra's pioneering works devoted to competitive behavior in population dynamics was published in first half of the 20^{th} century the problems of competitive dynamics are still actual and full of interest for many scientists.

Generally, from mathematical viewpoint, biological control has been modeled as a two-species interaction. In this case, the prey-predator or host parasitoid models ignore many important factors such as interactions between another species of same ecosystem, interactions with environment, etc. Arneodo et al. [1], have demonstrated that one can obtain chaotic behaviour for three species. In a 1988 paper Samardzija and Greller [2] propose a two-predator, one prey generalization of the Lotka-Volterra problem into three dimensions. The synchronization of trajectories of two attractors of this modifed, three-dimensional Lotka-Volterra equation, was performed by John Costello [3] using the Kapitaniak method.

On the basis of the Lotka–Volterra model, Rafikov et al. [4] analyzing relations between two soybean caterpillars (*Rachiplusia nu* and *Pseudoplusia includes*) in order to obtain a pest control strategy through natural enemies' introduction. The numerical simulations of the authors based on one prey – one predator Lotka–Volterra model showed that control strategy can maintain the pest population below injury level during long time. For three species, two preys – one predator Lotka–Volterra model, the analytical and numerical studies reveled that control strategies could not control the pest population below of the economic injury level. The pest control problem was resolved for two preys – two predators Lotka–Volterra model.

Over the last decade, there has been considerable progress in generalizing the concept of synchronization to include the case of coupled chaotic oscillators especially for biological systems. When the complete synchronization is achieved, the states of both systems become practically identical, while their dynamics in time remains chaotic [5-9]. Many examples of biological synchronization have been documented in the literature, but currently theoretical understanding of the phenomena lags behind experimental studies.

In order to formulate the biological control in this work the synchronization of two Lotka–Volterra with three species, one prey and two predators is presented.

MATERIAL AND MEHOD

Samardzija and Greller [2] proposed equations for a two-predator, one prey generalization of the Lotka-Volterra system as follows:

$$\begin{aligned} \dot{x} &= x - xy + Cx^2 - Azx^2 \\ \dot{y} &= -y + xy \\ \dot{z} &= -Bz + Azx^2 \end{aligned} \qquad (1)$$

Here x is the prey population, y and z are predator populations and A,B, C are positive constants.

For A=2,9851, B=3 and C=2 [3] the systems has chaotic behaviour. For initial conditions x_0=1, y_0=1,4 şi z_0=1 the strange attractor is given in figure 1.

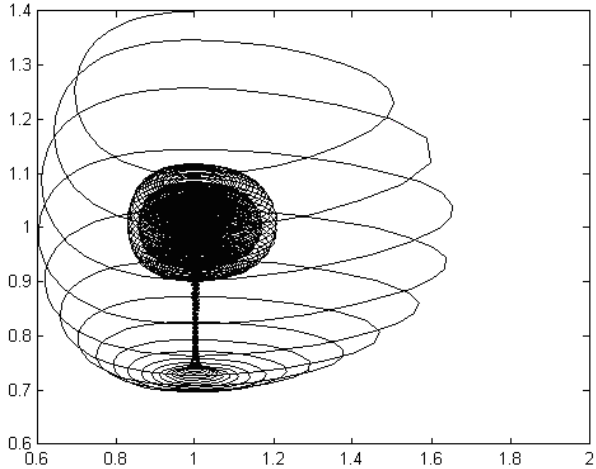

Figure 1 **Phase portrait of (x, y) for Samardzija and Greller system with one prey and two predators**

To synchronize two Lotka –Volterra systems whit three species we used a simple method for chaos synchronization proposed in [10-12].

If the chaotic system (master) is:

$\dot{x} = f(x)$ where $x = (x_1, x_2, ...x_n) \in R_n$

$$f(x) = (f_1(x), f_2(x).....f_n(x)) : R^n \to R^n$$

The slave system is:

$$\dot{y} = f(y) + \varepsilon(y - x)$$

where the functions $\dot{\varepsilon}_i = -\lambda_i (y_i - x_i)^2$ and λ_i are positive constants

RESULTS AND DISCUSSIONS

a) Case 1

The slave system for the system (1) is:

$$\begin{aligned}
\dot{x}_1 &= x_1 - x_1 y_1 + 2x^2 - 2.9851 z_1 x_1^2 + \varepsilon_1 (x_1 - x) \\
\dot{y}_1 &= -y_1 + x_1 y_1 + \varepsilon_2 (y_1 - y) \qquad (2) \\
\dot{z}_1 &= -3z_1 + 2.9851 z_1 x_1^2 + \varepsilon_3 (z_1 - z)
\end{aligned}$$

The control strength is of the form:

$$\begin{aligned}
\dot{\varepsilon}_1 &= -10(x_1 - x)^2 \\
\dot{\varepsilon}_2 &= -10(y_1 - y)^2 \qquad (3) \\
\dot{\varepsilon}_3 &= -10(z_1 - z)^2
\end{aligned}$$

Fig. 2, 3, 4 and 5 show the syncronization of the two Lotka –Volterra generalized systems (for one prey and two predators).

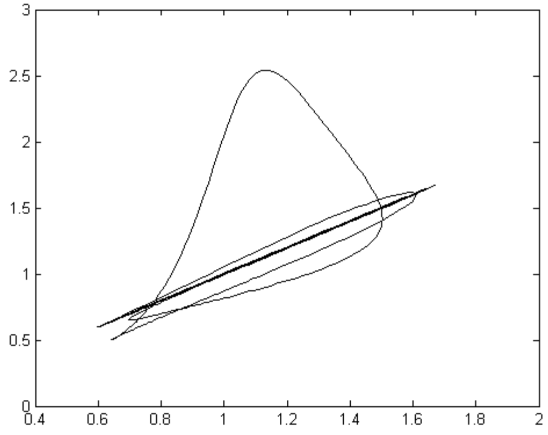

Figure 2 **Phase portrait of (x, x_1) for Samardzija and Greller system with initial conditions [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5; z_1(0) = 1; ε_1(0)=ε_2(0)=ε_3(0) = 1]**

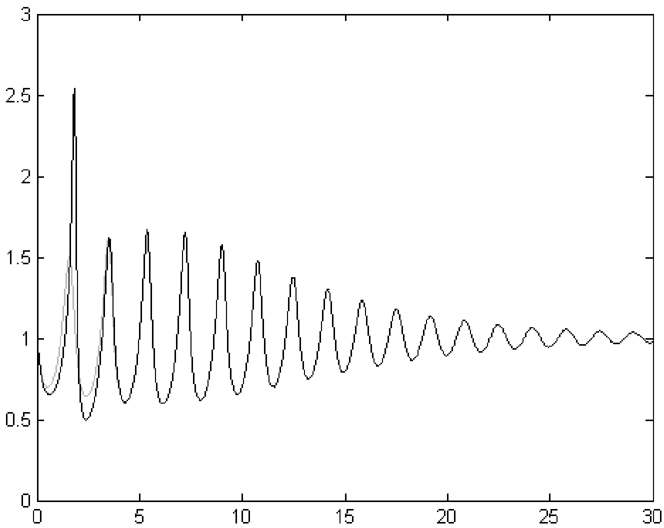

Figure 3 **x(t)- gray, x_1(t)- black [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 ; z_1(0) = 1; ε_1(0)=ε_2 (0)=ε_3(0) = 1]**

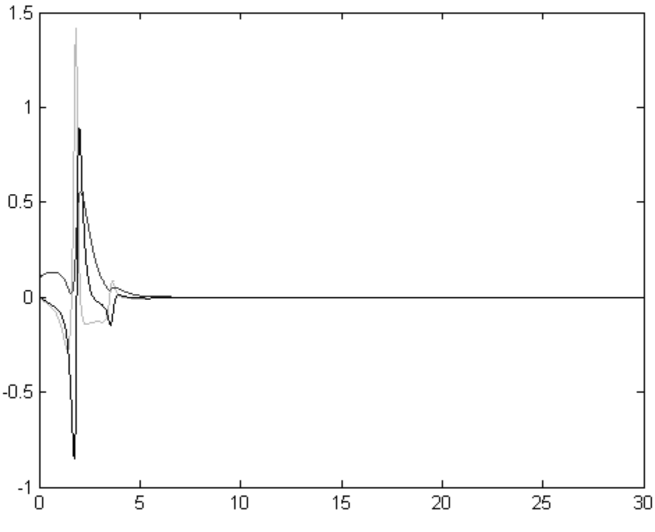

Figure 4 **Synchronization errors between master and slave systems [x(0) = 1; y(0) = 1.4; z(0) = 1; x_1(0) =1; y_1(0) = 1.5 z_1(0) = 1; ε_1(0)=ε_2 (0)=ε_3(0) = 1]**

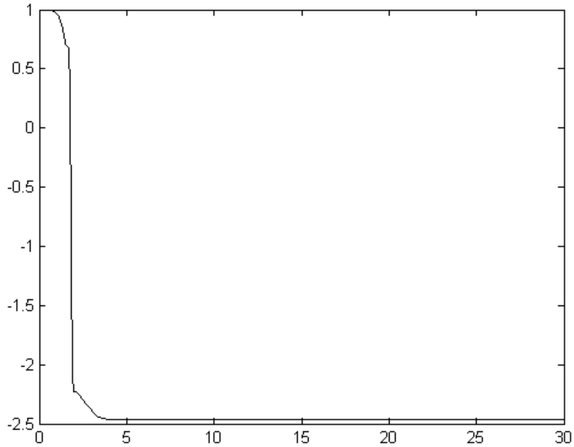

Figure 5 **The control strength ε_3 (t) [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5; z_1(0) = 1; ε_1 (0)= ε_2 (0)= ε_3 (0) = 1]**

b) Case 2

Debin Huang [15], by testing the chaotic systems including the Lorenz system, Rossler system, Chua's circuit, and the Sprott's collection of the simplest chaotic flows found that the coupling only one variable is sufficient to achieve identical synchronization of a three-dimensional system.

For the system (1), we achieved the synchronization if one controller is applied in the second and in the third equation of system; this means we interfere only on predator population. For example, if the controller is in the third equation, the synchronization is given in *figure 6* and *7*.

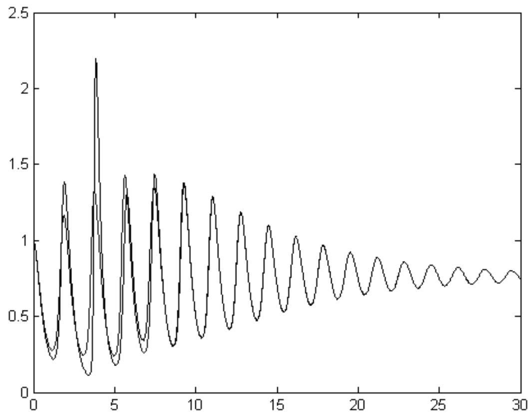

Figure 6 **z(t)- gray, z_1(t)- black [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 ; z_1(0) = 1; ε_3 (0) = 1]**

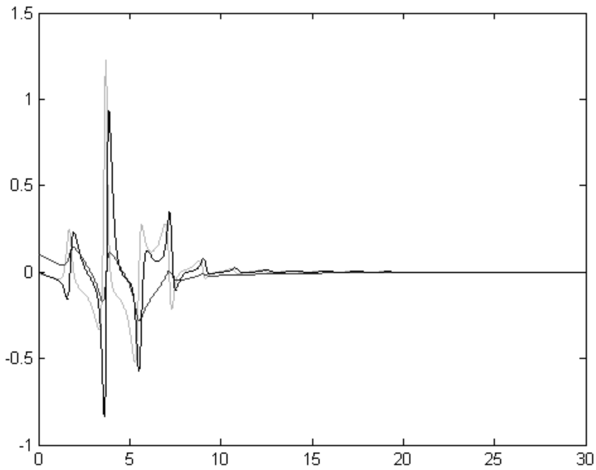

Figure 7 **Synchronization errors between master and slave systems [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 z_1(0) = 1; ε_3 (0) = 1]**

Therefore one controller can be used only for predators in order to control the all species; our results show that the synchronization is about three times faster for all four controllers than for one controller.

c) Case 3

An interesting situation can be obtained if we use one controller in the first equation of the system of the form: $\dot{\varepsilon}_1 = -0.1(x_1 - x)^2$. Then the prey population becomes constant and the first predator colapses, as figure 9 and 10 show.

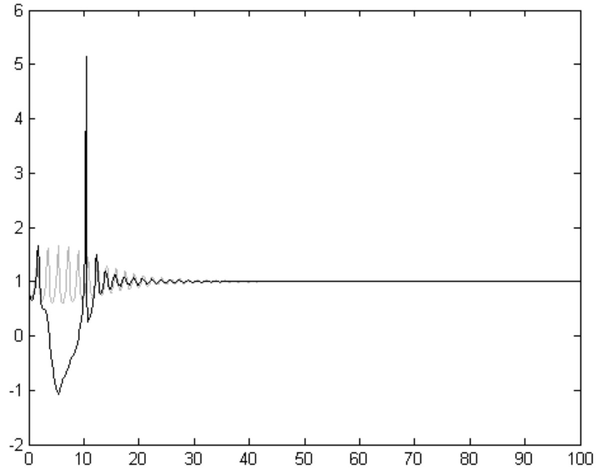

Figure 9 x**(t)- gray x_1(t)- black [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 z_1(0) = 1; ε_1 (0) = 1]**

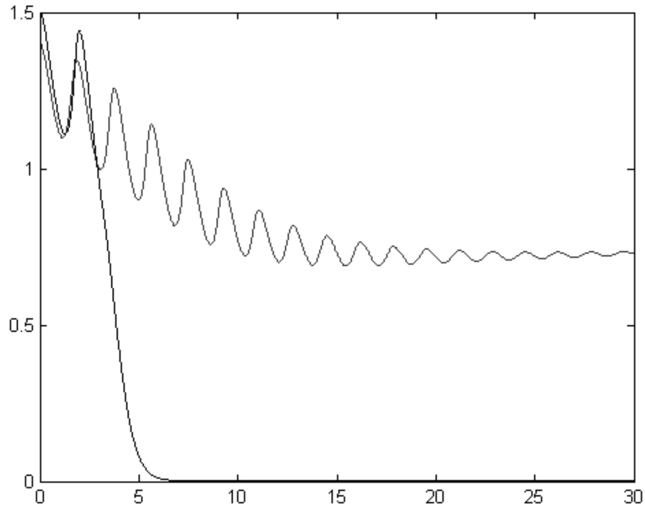

Figure 10 **y(t)- gray, y_1(t)- black [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 z_1(0) = 1; ε_1(0) = 1]**

In this case, the second predator is given in *figure 11*.

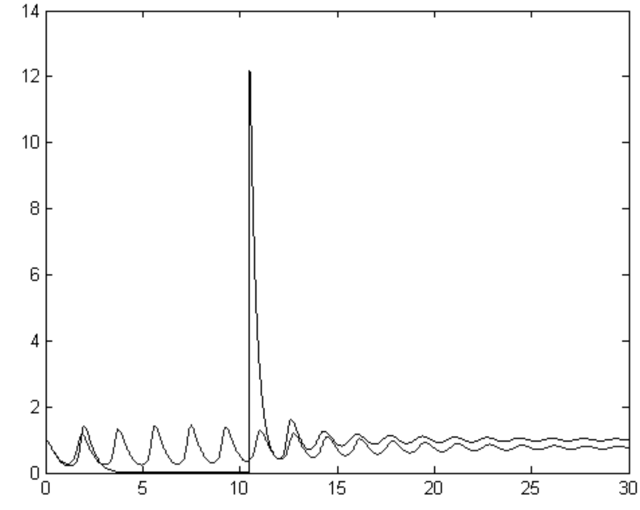

Figure 10 **z(t)- gray, z_1(t)- black [x(0) = 1; y(0) = 1.4 z(0) = 1; x_1(0) =1; y_1(0) = 1.5 z_1(0) = 1; ε_1(0) = 1]**

CONCLUSIONS

In order to formulate the biological control, the synchronization of two Lotka–Volterra systems with one prey and two predator is presented in this work. The transient time until synchronization depends on initial conditions of two systems and on the control number. Our results show that the synchronization is about three times faster for all three controllers than for one controller. The synchronization for all species is possible with one controller only if we interfere on predator population. The control method described in this paper is very easy and might be useful in the case of the other chaotic systems. By comparison with Costello's work when synchronization is possible but doesn't occurred before t = 3600, in our work the synchronization in the first case is obtained until t=10. We suggest that we can control the three species obtaining the synchronization of prey and predator population by varying the initial condition and the control strength.

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