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# A chemical control by fuzzy linear programming

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**Abstract**. This work proposes a chemical control to soybean aphid by fuzzy linear programming. The soybean aphid, *Aphis glycines* (Hemiptera: Aphididae), is an invasive herbivore to North America. in this paper we have propose a chemical control in the plantation when the prey population exceeds the economic damage threshold. On the other hand, the soybean aphid has become the most devastating insect pest of soybeans in the United States. Brazil is the second largest exporter of soybean at present, after the USA and before Argentina. According to the Bureau of Agriculture of the USA, it has been estimated that Brazil will be the largest soybean exporter in 2023.

***Keywords***: *fuzzy set, fuzzy linear programming, control.*

## 1. Introduction

This work proposes a chemical control to soybean aphid by fuzzy linear programming. The soybean aphid, *Aphis glycines* (Hemiptera: Aphididae), is an invasive herbivore to North America (McCornack et al., 2004) .

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The model includes a fuzzy predator-prey system in order to describe the interaction between the prey, *Aphis glycines* (Hemiptera: Aphididae) - the soybean aphid, and its predator, *Orius insidiosus* (Hemiptera: Anthocoridae) considering biotic (predator) and abiotic (temperature) factors, which affect the soybean aphid population dynamics, and a comparison between the fuzzy model and real data reported in the literature (Hunt, 2005) [see (Peixoto et al., 2016)].

An economic threshold was developed for chemical control, i.e., when an insecticide treatment is warranted. Economic thresholds for the soybean aphid have been developed and vary from 250 to 273 aphids per plant (Ragsdale et al., 2007). The control measures are not introduced before reaching the economic threshold.

We proposed in Peixoto et al. (2016) a fuzzy biological control to soybean aphid, that is, the model provides how often and how much to add the predators in the plantation by fuzzy rule-based system, instead using insecticides.

We proposed in Peixoto et al. (2015) a fuzzy control to soybean aphid, that is, the model provides how often and how much to apply the insecticides on the plants in a simple, intuitive and a direct way.

In this work we propose a chemical control to soybean aphid by fuzzy linear programming (Klir e Yuan, 1995). Thus, in this paper we have propose a chemical control in the plantation when the prey population exceeds the economic damage threshold and aphids population increasing.

The aim of this investigation is to propose a specific method to enhance current decision making tools to control this pest. On the one hand, the soybean aphid has still not found in Brazil. Therefore, before any eventual invasion, a predictive model to enhance control program is desirable. On the other hand, the soybean aphid has become the most devastating insect pest of soybeans in the United States. Brazil is the second largest exporter of soybean at present, after the USA and before Argentina. According to the Bureau of Agriculture of the USA, it has been estimated that Brazil will be the largest soybean exporter in 2023.

## 2. The mathematical model

The classical linear programmimg problem is to find the maximum (or minimum) values of he linear function under constraints represented by linear inequalities or equations, that is,

maximize (or minimize) $c^T x$

subject to $Ax \leq b$

$x \geq 0,$

where $x$ is a vector of variables, $A$ is called a constraint matrix, and the vector $b$ is called a right-hand-side vector. As is well know, many practical problems can be formulated as linear programming problems (Klir e Yuan, 1995).

Fuzzy linear programming is a family of optimization problems in which the optimization model parameters are not well defined, that is, the objective function and/or constraint coefficients are not exactly known and that some of the inequalities involved may also be subject to unsharp boundaries (Pedrycs e Gomide, 1998).

The optimization model associated with a linear programming problem in which only the right-hand-side numbers $B$ are fuzzy numbers [(Barros e Bassanezi, 2010), (Zadeh, 1965)] is formulated as follows:

max (or min) $c^T x$

subject to $Ax \leq B$

$x \geq 0.$

In this work, let $x$ denote the number of aphids population in the plant and $z$ the quantity of insecticide. Then the problem can be formulated as the following fuzzy linear programming problem:

min $z = 0.2x$

subject to $x \leq B$

$x \geq 0$

where $B$ is defined by

$$\begin{cases} 1, & x \leq 250 \\ \dfrac{700 - x}{450}, & 250 < x \geq 700. \\ 0, & x \geq 700 \end{cases} \tag{2.1}$$

Then, the fuzzy linear programming problem becomes:

min $\lambda - 1$

subject to $450\lambda - 0.2x \leq -250$

$450\lambda + x \leq 700$

$x, (\lambda - 1) \geq 0.$

## 3. Results and Conclusions

The problem has been modeled via Simplex Method in MATLAB®. Solving this classical optimization problem, we find that the minimum, $\lambda = 0.5587$, is obtained for $x = 448, 59$. The quatity of insecticide $z$ is then calculated by

$$\hat{z} = 0.2\hat{x} = 89.7$$

This model suggests that the quantity of insecticide was 89.7% of the quantity recommended by manufacturer. In this way, the model suggests that the quantity of insecticide may be lower than the quantity recommended by manufacturer.

The concern about the environment has been increasingly important. Currently, actions aimed at sustainable management of natural resources are goals. In general, pesticides are toxic, harmful to human health and the environment. One of the most common problems is the contamination of soil, groundwater, rivers and lakes. When the pesticide is used, it intoxicates all life present. Studies show the decrease in the number of pollinating bees and the destruction of bird habitat in environments where pesticides are used. The abusive use of insecticides may lead to an increase number of pests because pests become more resistant, requiring stronger pesticides that will damage the environment even more and will kill the pests' natural predators (Pimentel e H. Lchman, 1993).

In this way, the model suggests that the quantity of insecticide may be lower than the quantity recommended by manufacturer. Besides, low-quantities of insecticides from that recommended by the manufacturer may be effective. On one hand, there are the costs for each application. On the other hand, there should be a concern about the environmental damage caused by the abusive use of insecticides in the plantations.

We will develop further studies on simple and specific method using a fuzzy rule-based system to help the implementation of an integrated pest management system of this one.

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