# Application of Non-Linear Programming in Apple Orchards Pest Control

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## ABSTRACT

Toxicity of an caricide and an insecticide was investigated against the two species of mites, *Panonychus ulmi* (Koch) and *Tetranichus urticae* (Koch) and one of their predatory mites, *Typhlodromips swrirskii* (Athias-Henriot) under laboratory conditions. Standard bioassay's procedures through non-linear programming (NLP) approach were used to determine the efficiency of two pesticides mixture on the predatory mite. In contact bioassay tests, 0, 200, 300, 400 and 500 µl $L^{-1}$and 0, 100, 200, 250 and 300 µl $L^{-1}$ of fenpyroximae and thicloprid were employed against the three mite sprcies, respectively. Mortality rate was recorded 72-hour post treatment. Based on the mathematical programming framework, the most optimum concentration in the mixture of fenpyroximae and thicloprid was 86 µl $L^{-1}$ and 4 µl $L^{-1}$, respectively. In addition, the proposed non-linear programming model was solved by the standard simplex algorithm. The revenue obtained was higher than that of the corresponding conventional pest-control measures. The model produced an optimal apple production scheme that gives higher income than that obtained from the conventional grower's plan. The NLP approach had the total production cost (10,105,600 R), while based on conventional pesticide's application the total cost was (18,700,000 R). The cost difference was 45.96 percent. It could be suggested that the non-linear programming model was a useful tool for apple orchards integrated pest management program.

**Key words:** Apple orchards, Biocontrol, Mites, Non-linear programming, Pesticides mixture.

## INTRODUCTION

Horticulture has been one of the profitable and faster growing agricultural sectors over the two past decades in Iran (Management of plazas of fruits and vegetables, 2012). Although the horticulture industry is growing constantly, various arthropod pests are major challenges, which could be constraint horticulture pervasive development. Therefore, controlling them with pesticides' application is an inevitable measure in apple production operation. Pesticides are a common tool in pest management strategy across the world (Kos *et al.,* 2009).

The two spotted spider mite *Tetranychus urticae* Koch, as the most polyphagous species within the family Tetranychidae, (Migeon and Dorkeld, 2010) and the European red mite *Panonychus ulmi* Koch (Acari: Tetranychidae) (Elizabeth *et al.,* 2007) are economically important pests in many cultivated plants in greenhouses and open fields all over the world. *P. ulmi* is most commonly a mite pest on apple, pear, plum, prune and cherry (Elizabeth *et al.*, 2007). Spider mite's problems often increase when natural enemies are destroyed by applications of broad-spectrum insecticides, applied against other pests (Mainul Haque *et al.,* 2010).

Several species of naturally-occurring insects and mites prey on spider mites (Enkegaard *et al.,* 1997 and Messelink *et al.*, 2008). One of them is the generalist predatory mite, *Typhlodromips swirskii* (A.-H.), which belongs to the Phytoseiidae family. It is found in the wild in the eastern Mediterranean region, *i.e*. Israel, Cyprus and Egypt. *T. swirskii* preys on the first larval phase of thrips, eggs and initial larvae of both glasshouses whiteflies, in addition to the younger phases of two-spotted spider mite the broad mite (Maanen *et al.*, 2010).

In the real world, competition among producers of agricultural products is intensively high. The growers very often have been encountered with the problem of how to select the most appropriate chemically pest-control measures that significantly contribute to expected sustainable profitability. In response to this enquiry and resolving such a challenge, a non-linear programming model was developed by selecting a combination of pesticides and pests under commercial orchard's conditions. The logic behind using NLP approach is Ozsan *et al.* (2010) claimed that mathematical programming framework was an appropriate analytical approach which could be useful in determining an optimal practice that satisfies the constraints and requirements under current situation. NLP framework has been used in identifying and optimization of limited production resources, under restricting conditions to obtain the most feasible benefit (Han *et al.*, 2011).

The adverse impact of pesticides on natural enemies can be mitigated through choice of pesticides, dosage, or timing of pesticide application (Galvan *et al.*, 2005). In an attempt to articulate an

NLP model, the optimal mites control schedule for pesticide applications on apple orchard was based on the assumption that pest mortality must be at least 50% for each treatment. The non-linear programming optimal scheme integrated the conventional pesticide's mixture with reduced rate. The mixture of pesticides was applied at weeks 2 and 8. This non-linear programming framework was based largely on the resource's prices and pesticides application rates, and mortality rate, from practical point of view could differ among producers and orchard's locations as well. Therefore, this program is flexible and could be adjusted as the prices of pesticides and application inputs change. The costs of using pesticides include economic product costs and environmental costs. The application cost of this program provided the minimized pesticide cost and less environmental pollution as well. This practice leads to considerable decrease the production cost of apple in the orchard which is 5317 RR per Kg for total 12 weeks' cycle.

In the present study the optimal doses in the mixture of two pesticides, fenpyroximate and thiacloprid, was estimated for maximization rate of mortality of pest mites (more than 50%) and minimization rate of loss of predatory mite (less than 50%) through non-linear programming approach. This paper first presents the optimization model based on NLP and then the results of the application of the model to the case study.

## MATERIALS AND METHODS

### Rearing of mites and predatory mite

*T. urticae* and *P. ulmi* were collected from apple orchards by any history of pesticide's application in Urmia, Iran. Rearing of these mites were conducted on three-year-old apple trees, Golden Delicious cultivar, were used the all experiments. The colony of *A. swirskii* was purchased from Koppert Biological Systems (Swirski-Mite LD®; The Netherlands) in 2014. The predators have been maintained on leaves of apple that infested with *T. urticae* or *P. ulmi*. The stock cultures of pest mites and predatory mite were maintained in an environmental chamber that was controlled at 25ºC, 60–70% RH and 16 h (L): 8 h(D) conditions.

### Chemicals tested

Thiacloprid, [3-[(6-chloro-3-pyridinyl) methyl]-2-thiazolidinylidene] cyanamide, (Calypso® 48% SC) and fenpyroximate, tert-butyl (*E*)-*E*-(1,3-dimethyl-5-phenoxypyrazol-4-ylmethyleneamino-oxy)-*p*-toluate (Ortus® 5% SC) were purchased from Bayer.

### Toxicity bioassays

In contact bioassay tests, commercial formulation of fenpyroximate and thiacloprid were applied against adult female mites at doses of 0, 200, 300, 400 and 500 µl $L^{-1}$ and 0, 100, 200, 250 and 300 µl $L^{-1}$, respectively. Each dose was replicated four times, with 10 individuals per replicate. Required solutions were prepared in distilled water. All experiments were conducted in the laboratory at 25 ± 0.5ºC, 50±5% RH and a photoperiod of 16:8 h (L:D). The concentrations of the pesticides were chosen based on the maximum field recommended concentration (MFRC) of these commercial compounds in Iran. The bean leaf discs were dipped in the tested pesticides' solution for 10 s and allowed to dry for about three h. The control leaf discs were dipped in distilled water. Mortality rate was recorded after 72 h of exposure. Adult mites were considered dead if they did not move when prodded with a soft paint brush.

### Non-linear programming model

The mathematical programming model consisting of three major components: an objective function for maximization of net return, a set of linear constraints and a set of non-negativity constraints was developed (Gadge *et al.*, 2014).

The model was formulated to a mixture of the different pesticides, in order to maximize the mortality rate of pest mites from the loss of predatory mite and minimize pesticide cost.

$n$ : No. of pesticides $\quad i = 1,2,..,n$

$m$ : No. of pests $\quad j = 1,2,..,m$

$l$ : No. of predators $\quad k = 1,2,..,l$

$x_i$ : Log of dose of pesticide $i$

$Pa_{ij}$ : Probability of the effect of pesticide $i$ on pest $j$

$Ps_{ik}$ : Probability of the effect of pesticide $i$ on predator $k$

$maxdose_i$ : Maximum log of dose of pesticide $i$

$$\text{Min } z = \sum_{i=1}^{n}\sum_{k=1}^{l} Ps_{ik} \qquad (1)$$

S.t:

$$Pa_{ij} = f(x_i) \quad \forall i = 1,\dots,n \quad \forall j = 1,\dots,m \qquad (2)$$

$$Ps_{ik} = f(x_i) \quad \forall i = 1,\dots,n \quad \forall k = 1,\dots,l \qquad (3)$$

$$0.5 \le Pa_{ij} \le 1 \quad \forall i = 1,\dots,n \quad \forall j = 1,\dots,m \qquad (4)$$

$$0 \le Ps_{ik} \le 0.5 \quad \forall i = 1,\dots,n \quad \forall k = 1,\dots,l \qquad (5)$$

$$\sum_{i=1}^{n} c_i x_i < C_T \qquad (6)$$

$$x_i \ge 0 \quad \forall i = 1,\dots,n \qquad (7)$$

Equation number 1 indicates the target of function that reduces the probability of the influence pesticide on predators. Equation number 2 demonstrates the relationship between the probability of the influence of the pesticide on pest and dose of pesticide. Equation number 3 shows the relationship between the probability of the effect of the pesticide on

Table (1): Pesticide types, rate range, price, and price per application

| Name | Type | Rate range per 100 gallons of water (R) | Price (R) | Cost per application | Total per application (R) |
|---|---|---|---|---|---|
| Calypso® 48% SC | Insecticide | 420 | 3,000,000 | 3,000,000 | 5,000,000 |
| Ortus® 5% SC | Acaricide | 420 | 900,000 | 900,000 | 2,900,000 |

*The price per application is based on the assumption that all the apple trees were 15-year-old
SC: suspension concentrate; R = Rial (Iranian currency) and Exchange rate is as follows: 1 USD = 29857n IRR

Table (2): Pesticide types, mortality percentage, application limits and constraints

| Name | Type | Mortality ercentage | Application limits | Constraints |
|---|---|---|---|---|
| Calypso® 48% SC | Insecticide | 85 | Less than 4 per year | App. Time ≤ 2 |
| Ortus® 5% SC | Acaricide | 75.5 | Less than 4 per year | App. Time ≤ 2 |

Note: Source of relative efficiency mortality is (WAANRRCPR). The source of application limits are the labels of pesticides. SC: suspension concentrate

predator and dose of pesticide. Limitation 4 confirms the probability of the effect of pesticide on pests is more than 50 percent. Limitation 5 certifies the probability of the effect of pesticide on predator is less than 50 percent and limitation 6 also shows that the cost of the spraying should not be more than the allocated amount. Limitation 7 certifies non-negative variables of the dose of pesticides.

**Application limits constraints to conventional pesticides**

As the application of pesticides affects environment and human health, there is great interest to reduce pesticides use. To achieve such goal, the direct way is to reduce pesticide application as much as possible. In this line tables (1 and 2) show application limit constraints to these conventional pesticides.

**Constraints to reassure mortality rate of targeted pest**

In the NLP model, in general equation which depicts the percent of mortality after pesticides' application, total mortality rate and relative efficiency of pest mortality are based on West Azaerbaijan Agricultural and Natural Resources Research Center Project's Reports (WAANRRCPR). Over thirty years, this center has been the resource of supplying pest management guideline in the county.

## RESULTS AND DISCUSSION

In the present study, the most optimum doses in the mixture of the two pesticides (i.e. fenpyroxymate and thiacloprid) were estimated assuming non-linear programming. The following results and models describe the toxicity of fenpyroxymate (recommended dose: 0.5 L per 1000 $L^{-1}$) and thiacloprid (recommended dose: 0.3 L per 1000 $L^{-1}$) on *T. urticae*, *P. ulmi* and *A. swirskii*. The developed model was solved using MS-Excel®, Minitab and Lingo11 software.

Number of predator: 1, Number of pests: 2,
Number of pesticides: 2

$$\text{Min } z = Ps_{11} + Ps_{21}$$

S.t:

The regression equations are:

For *T. urticae* and fenpyroxymate:

$$Pa_{11} = 1.090 - 2.443x_1 + 1.652x_1^2 - 0.2834x_1^3$$

For *P. ulmi* and fenpyroxymate:

$$Pa_{12} = 2.476 - 4.825x_1 + 2.895x_1^2 - 0.4865x_1^3$$

For *T. urticae* and thiacloprid:

$$Pa_{21} = 2.163 - 3.737x_2 + 1.981\,x_2^2 - 0.2902x_2^3$$

For *P. ulmi* and thiacloprid:

For *A. swirskii* and fenpyroxymate:

For *A. swirskii* and thiacloprid:

$$\text{Min } z = Ps_{11} + Ps_{21}$$

S.t:

$$Pa_{11} = 0.7238 - 1.831x_1 + 1.384x_1^2 - 0.249x_1^3$$

$$Pa_{12} = 1.265 - 2.780x_1 + 1.849x_1^2 - 0.3187x_1^3$$

$$Pa_{21} = 3.223 - 5.366x_2 + 2.771\,x_2^2 - 0.4105x_2^3$$

$$0 \leq Ps_{11} \leq 1$$
$$0 \leq Ps_{12} \leq 1$$
$$(6 \times 10^{-5} \times 10^{x_1}) + (3 \times 10^{-4} \times 10^{x_2}) \leq 0.005$$
$$Pa_{11} = 0.5484610$$
$$Pa_{12} = 0.5000000$$
$$Pa_{21} = 0.9201869$$
$$Pa_{22} = 0.5072043$$
$$Ps_{11} = 0.4061527$$
$$Ps_{21} = 0.1991479$$
$$x_1 = 1.920819 \qquad x_2 = 0.5968301$$

With Taking the Logarithm:

$$x_1 = 86\ \mu l\ L^{-1} \qquad x_2 = 4\ \mu l\ L^{-1}$$

For extrapolation of laboratory results to field conditions, the pesticide dose should be increased up to eight-folds to achieve similar mortality to corresponding mortality rate under lab conditions (Barile *et al*., 2008). This is a crucial point in terms of cost reduction under field conditions. Based on such an assumption the NLP model might provide conditions for achieving 45% cost reduction.

In conclusion, Using non-linear programming techniques for different kinds of planning and analysis, based on the optimization in various fields such as agriculture, has a long history and extensive. Generally, the non-linear programming is a mathematical technique to solve a problem with particular traits. The main objective in the non-linear programming is maximization or minimization of an objective function. There are many reasons for the study and application of the non-linear programming. The first is due to problems related to the allocation of limited resources. Although, the input data required by the non-linear programming is similar to other methods, but the calculations needed to solve problems in non-linear programming, are easier to access than other methods. Other methods for solving complex problems are expensive and difficult. However, they can be easier achieved by non-linear programming. The second, using ofnon-linear programming gives information in the best possible way to allocate resources and best programs in the production, marketing and finance.

The non-linear programming is an efficient program, where the model used in the present study is applicable on pest-control programs under various conditions. It can be also used even in the case of agricultural inputs. In this model, as a simplex algorithm used and is an affordable, flexible and depending on any user demands and requirements. This model is not function to time, location, pest or other factors. Due to originality and lack of correspondent references pertain discussion is far-fetched.

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