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Applications of Neuro-Fuzzy Classification, Evaluation and Forecasting Techniques in Agriculture

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ABSTRACT

Aim of the present article is to show the results obtained from the application of neuro-fuzzy methodology in the solution of agriculture problems like the Bactrocera Oleae (olive fly) infestation in the Liguria region olive grows.
The research is focused to create an informatic decisional instrument to support experts in the applications of Integrated Pest Management strategies against the Bactrocera Oleae infestation. The system will suggest types of treatments for each monitored farm in order to optimize the quality of the olive oil and improve the economic and environmental impact of these treatments.
Statistical and forecast analyses on data sets referred to agronomic case studies, like the growth of olive fly, are actually made using standard and model approaches like analytical; these dates instead present characteristics (big variability and non-linearity) which make them complex to be treat mathematically. Agronomic research needs to introduce new analysis techniques of taken dates and information, for example neuro-fuzzy methodologies that allow a large use of infestation dates with a good flexibility degree.

1. BIOLOGICAL INTRODUCTION to the PROBLEM

The definition of an agrarian product quality is linked to its geographic and chemical-physical characteristics but for a good quality classification other variability factors like growing and transformation techniques shall be considered.
The olive production and the oil quality are strongly influenced by the olive fly infestation and by the used defence techniques, therefore it is mandatory to carry out studies on the growing cycle of Bactrocera Oleae, annual behaviour of infestation, monitoring and control methodologies.
When the olive has overtaked the phenological phase of hard stone, the female lays eggs and after few days the larva comes out; larva presents 3 different growing stages (L1,L2,L3) that grow up eating the olive. When the larva is mature comes out from olive, falls to the ground and becomes a pupa.
The olive fly in Liguria developes 3 complete generations per year and sometimes can begin a fourth if the climatic conditions are favourable; the beginning of infestation is

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linked to annual variation of median temperature, to the region climate and micro-climate.
The present project started on March 2000 monitoring and collecting data from a several number of oil farms in Liguria area.
The monitoring plan shall test the presence and growth of harmful bugs, following the dinamic infestation in the olive-grove to define the best treatment.
Monitoring is made in two phases:

- adult capture weekly made with plexiglass trap, the experience shows that is not possible to find a correlation between the entity of capture and the infestation
- olive collection allows the estimation of infestation percentage in the olive-grove.

The actual defence methodology is to apply the treatments only if necessary, and infestation studies allow to carry out aimed treatment, with low quantity of pesticide to reduce the environment impact.

2. APPLICATION of NEURO-FUZZY METHODOLOGY

The analysis of biological data of the fly and of environment data where the fly grows, allows to create a simulation model of ‘fly-tree-environment’ system and therefore of the infestation development.
Since this system is not linear, very variable and difficult to be represented by traditional methods that make use of mathematical equations, as an alternative the present work has used the WRBF-n neural network [2], which have a big flexibility and can learn from experience thanks to training alghoritms.
A WRBF-n neuron (weighted radial basis function) is an unification of different paradigms like P-neuron, wavelet neuron and fuzzy system; the big advantage of this neuron is that unites a training alghoritm with the experience of experts as fuzzy rules.
Each WRBf neuron is characterized by the following parameters:

- an order n that is the neuron’s metric
- a weight matrix w
- a centre matrix c
- an optional bias θ
- an activation function F(z)

The mathematical model of a WRBF-n neuron is :

$$y_j = \begin{cases} F_j\left(\sum_i \left(x_i - c_{ji}\right) \cdot w_{ji} + \Theta_j\right) & n = 0 \\ F_j\left(\sqrt[n]{\sum_i \left|x_i - c_{ji}\right|^n \cdot w_{ji} + \Theta_j}\right) & n \neq 0 \end{cases}$$

3. CHARACTERIZATION of INFESTATION with WRBF-NETWORK

The study of infestation dynamic during a complete year, shows the growth of 3 different generations of fly , where generally the level of one is lower due to the lower

temperature. Often the three generations are not so evident due to evolving of the climatic conditions.
In the Figure 1 there is a real dicrete behaviour of the infestation.

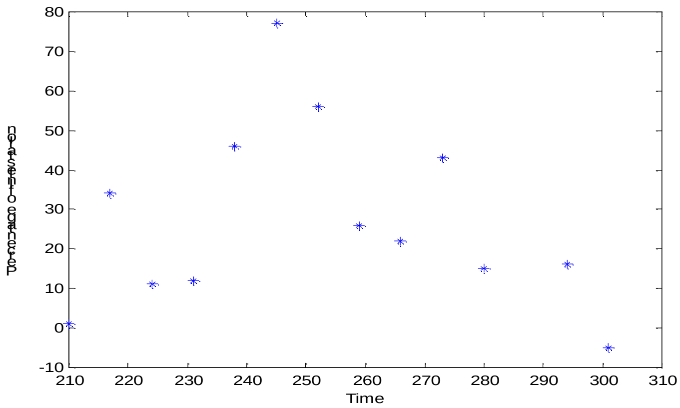

Figure 1.- **Real infestation.**

To make a clustering for kinds of infestation is important to describe simply a curve using known math functions that allow to extract a limited numbers of parameters which can describe very well the curve.
The tests carried out with the on the field gathered data have shown that the 3 generations can be satisfactorily described with 3 gaussian curves and each one of them characterized with 3 parameters like:
- the center of gaussian function (sample corrisponding to the maximum infestation)
- the height of gaussian (value of maximum entity of infestation)
- the dispersion of gaussian (width of curve)

The characterization of curve has been made building a two layers feed forward, neural WRBF-n network with a training back-propagation algorithm; the network has one input (the time) and gives as output the characterized infestation.
In the hidden layer there are 3 WRBF-2 neurons, (or WRBF-3 neurons), one for each generation, the output layer is made of only one linear neuron WRBF-(+∞) to interpolate on the max of each curves; the tests have been made also using a WRBF-0 to interpolate on the sum of curves but the results are not so good like with infinite order.
The network makes the characterization considering initially each measure with the same reliability (0.9) (see par.4) and then associating to each measure the relative reliability computed applying suitable entomological rules, this methodology is described in the next point.
The results obtained are very encouraging in fact the standard error between target (real infestation) and the output of the trained network is quite low.

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Here below the results obtained by 5 farms in Liguria.

Farm	Standard error with WRBF-2	Standard error with WRBF-3
F1	3.63 %	3.01 %
F2	2.88 %	1.44 %
F3	7.48 %	7.3 %
F4	3.47 %	2.25 %
F5	1.61 %	2.45 %

In Figure 2 an example of the characterization of the infestation in a farm, using a WRBF-3 network. On the x axis there are the day of sample and on the y axis the percentage of infestation.

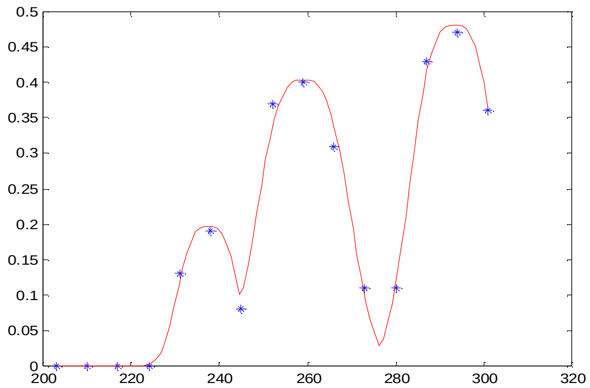

Figure 2.- **Infestation of F2 : the output of the WRBF-3 network is the continuos line.**

4. NEUR-FUZZY NETWORKS for RELIABILITY of INFESTATION MEASURES

The measures of infestation performed on the samples of olives are often affected by errors, therefore it is mandatory to establish a method to evaluate the error and to associate a reliability degree to each measure.
A way to understand the reliability level of an infestation measure, had been identified two kinds of errors based on comparison of fruit fly infestation data among monitoring at one week distance; the two kind of errors are unexpected increase and unexpected decrease of the infestation.
With the values of P, L1, L2 and L3 for active and inactive stages together Eh, exit holes and Tot sum of all the stages of fly growth, are calculated 5 different equations and the result of each one is evaluated trough 4 rules to determine the relative reliability in terms of : no error, low, medium and high error.

The minimum among these results represent the final reliability of the measure.
Here in the following an example of four fuzzy rules for one equation :
IF '$(Pa + Pi)_{(t)} - (Pa + Pi)_{(t-1)} + L3a_{(t-1)}$' is 'no error' THEN 'reliability' is 'high'
IF '$(Pa + Pi)_{(t)} - (Pa + Pi)_{(t-1)} + L3a_{(t-1)}$' is 'low error' THEN 'reliability' is 'medium'
IF '$(Pa + Pi)_{(t)} - (Pa + Pi)_{(t-1)} + L3a_{(t-1)}$' is 'medium error' THEN 'reliability' is 'low'
IF '$(Pa + Pi)_{(t)} - (Pa + Pi)_{(t-1)} + L3a_{(t-1)}$' is 'big error' THEN 'reliability' is 'very low'

For each rule, it has been created a fuzzy system by a WRBF neural network with three layers in which the first hidden layer contains so many neurons as the number of rules (4) the second one is a normalization layer for the first step of de-fuzzyfication and the output layer has one linear neuron corresponding to the value of reliability.
In Figure 3 it is shown the entire system for reliability of measure.

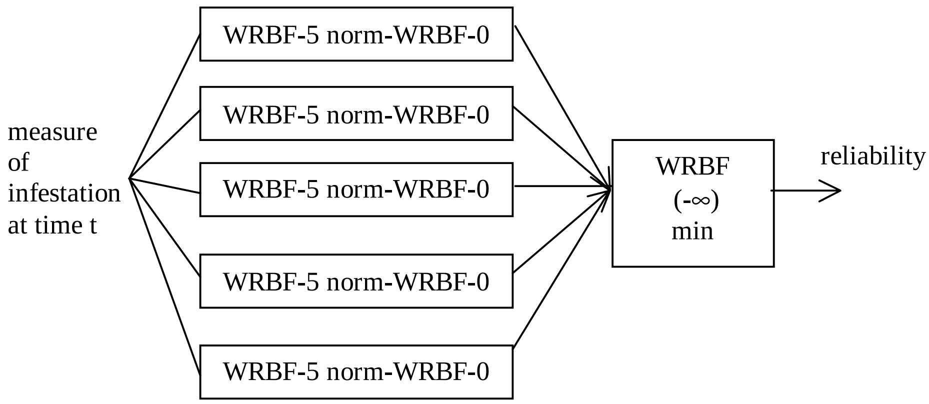

Figure 3.- **System for reliability**

The reliability evaluation system had been tested on a large number of farm and the results compared with the crisp applications of the tests on the same data infestation performed by the agronomists. The agreement between the results is very good and encourage for the future applications in other field.
Below there are two examples of results obtained by the applications of the neuro-fuzzy system; the low reliabilities noticed by the system (0.1) have been confirmed by the agronomists.

Day	**Egg**	**L1a**	**L1i**	**L2a**	**L2i**	**L3a**	**L3i**	**Pa**	**Pi**	**Eh**	**Reliability**
1999-9-2	4	2	0	7	2	10	4	3	8	6	0.9
1999-9-9	9	8	2	0	0	0	0	0	0	0	0.1

Day	**Egg**	**L1a**	**L1i**	**L2a**	**L2i**	**L3a**	**L3i**	**Pa**	**Pi**	**Eh**	**reliability**
1999-8-5	4	2	0	7	2	10	4	3	8	6	0.89
1999-8-12	9	8	2	0	0	0	0	0	0	0	0.1

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There is a good advantage in using this automatic system because the time that should spend the agronomists for estimate the reliability of all measures for each farm is very large.
The estimated reliability is associated at each measure date and than used in the training algorithm of the WRBF neural network of para.2, as a product factor; this results in a better characterization of infestation curve.
The standard error between the target and the output of the trained network is generally worst than that one obtained by using same reliability for each measure, but the parameters that describe the curve are more reliable than the previous.
Actually it is in study a neuro-fuzzy system to detect the reliability of infestation at generation level.

5. CONCLUSION

Actually, it is studiing the clustering of the infestation curves using the parameters obtained by the characterization with the WRBF neural network and the neuro-fuzzy system for the reliability.
The clustering will reduce to a small number of classes the tipologies of infestation and so the treatment to use against the infestation.
The results are validating with experimental data and in future a WEB-based environment will be developed for acquisition, processing, classification, forecast and management of disinfestation treatments.
The possibility to apply the same methods to other agricultural processes and problems will also be analyzed.
The program will finish with the availability of a decision-support environment tested on the olive fruit fly infestation.

6. REFERENCES

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