Use of fuzzy control rules for decision-making about appropriateness of fungicide application against grape downy mildew
Mediterranean vine mealybug
American grapevine leafhopper
Grape berry moth

Pests (synthetic risk indicators)
Grape Downy mildew is a disease of major importance worldwide and fungicide applications are necessary to avoid yield losses.

Fungicide applications begin in late April.
14-18 applications/year.

- With calendar-based schedule there is a huge amount of input (sometime useless).
- A key role in the epidemic is played by the primary infections.
Reduction of the number of treatments

5 ha plot of cv. Barbera in north-western Italy

9

5

Farm

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AIM of this work was to test a fuzzy logic set of rules in order to combine multiple criteria into a single decision support.
✓ **Classic logic** assigns binary values, such as 1 for true and 0 for false, to a variable which makes logical reasoning exact;

✓ In **fuzzy logic**, by contrast, truth is represented in relative terms, referred to as degrees, which allow an approximated inference rather than an exact conclusion. In fuzzy logic, a variable can be expressed in natural language, such as “slow” or “fast”, to simulate physical processes;

✓ A **membership function** assigns a degree of membership between 0 and 1 to the value of a variable;
Consider $X = [0, 100\%]$ (range of percentage) and a function to represent the fuzzy set corresponding to the concept “small percentage”:

$$A(x) = \begin{cases} 
1 & \text{if} \quad 0 \leq x \leq 20\% \\
3-x/10 & \text{if} \quad 20\% < x \leq 30\% \\
0 & \text{if} \quad x > 30\%
\end{cases}$$

- This function specifies that values smaller than 20% are completely compatibles with the mining of small percentage, but also values from 20% - 30% are compatibles, but with decreasing degree of compatibility.
- Values greater than 30% are not compatibles at all with the meaning of “small percentage”.
Use of a fuzzy logic approach

- BBCH
  - Low
  - High

- Infection threshold (%)
  - Low
  - Alert
  - High

- Residual efficacy (%)
  - Low
  - High

- Sporulation (h)
  - Low
  - High

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 114, 116, 118, 120

0, 12

0, 2, 4, 6, 8, 10

0, 10, 20, 40, 60, 80, 100, 120, 140, 160

0, 20, 40, 60, 80, 100, 120, 140, 160

0, 2

0, 4, 6, 8, 10

0, 2, 4, 6, 8, 10, 12
Use of a fuzzy logic approach

For the triangular membership function:

\[
\text{HIGH}(x) = \begin{cases} 
1 & \text{if } x > d2 \\
(x-d1)/(d2-d1) & \text{if } d1 \leq x \leq d2 \\
0 & \text{if } x < d1 
\end{cases}
\]

\[
\text{LOW}(x) = \begin{cases} 
0 & \text{if } x > d2 \\
(d2-x)/(d2-d1) & \text{if } d1 \leq x \leq d2 \\
1 & \text{if } x < d1 
\end{cases}
\]

For the trapezoidal membership function:

\[
\text{ALERT}(y) = \begin{cases} 
(y-c1)/(c2-c1) & \text{if } c1 \leq y \leq c2 \\
(y-c4)/(c3-c4) & \text{if } c3 \leq y \leq c4 \\
1 & \text{if } c2 \leq y \leq c3 \\
0 & \text{if } y < c1 \text{ or } y > c4 
\end{cases}
\]
Use of a fuzzy logic approach
The fuzzy logic was used under three different growing conditions for three seasons (2011-2013)

Comparison of the expert user’s fungicide schedule (that provided a full protection of the vines) with the one provided by the fuzzy set
Canneto Pavese - 2013

Expert user

Fuzzy logic

False alarm (wrong weather forecasts)
**Bayesian analysis**

### Treatment (Fuzzy)

<table>
<thead>
<tr>
<th>Treatment (Expert)</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>20.8%</td>
<td>1.1%</td>
</tr>
<tr>
<td>No</td>
<td>3.5%</td>
<td>74.6%</td>
</tr>
</tbody>
</table>

- **TPP** = 0.952
- **FPP** = 0.045
- **FNP** = 0.048
- **TNP** = 0.955

- **J (Yuden index)** = 0.967
- **Overall accuracy** = 0.975

**Posterior probability that:**
- the Fuzzy suggests to spray when the Expert would = 0.855
- the Fuzzy suggests not to spray when the Expert would not = 0.986
- the Fuzzy suggest to spray when the Expert would not = 0.145
- the Fuzzy suggest not to spray when the Expert would = 0.014
Expert users applied fungicides against all predicted infection periods and this resulted in optimal disease control.

Expert users did some unjustified treatment because few predicted infections did not occur (inaccurate rain forecasts).

The fuzzy logic allowed a beginner to take the same decisions than an expert user.

Thus the fuzzy logic approach can be considered a good way in order to make a multi-criteria decision-making process simpler.
Thank you!