DESIGN OF AN INDICATOR OF VINE VIGOR POTENTIAL CONFERRED BY SOIL (VIPOS), USING A FUZZY EXPERT SYSTEM

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ABSTRACT

Winegrowers must adapt more and more their viticultural practices in order to evolve toward a sustainable viticulture, to be competitive and to improve both the production methods and the quality and typicalness of wines. In this context, 'Terroir' studies in Loire Valley vineyards have allowed to build decision aid maps that can be used directly by growers to adjust their practices. We focus here on the vigor potential conferred by soil (VIPOS) that especially allows adapting the choice of the rootstock. An algorithm had previously been proposed by Morlat (2001) to estimate VIPOS according to three main influencing variables: water holding capacity of the soil, gravel percentage on the soil profile and parent rock hardness. Nevertheless, the VIPOS estimation, based on this algorithm, had to be completed by expertise. The objective of the paper is to present a new method to estimate VIPOS using a fuzzy expert system that allows having an automatically continuous estimation.

KEYWORD

Vine vigor – Fuzzy expert system – Soil characteristics – Decision aid maps

INTRODUCTION

Vine comportment is influenced by different soil factors. Main effects concern vine water supply, earliness and vigor potentials conferred by the soil (Jackson and Lombard, 1993; Trought *et al.*, 2008). In the characterization of viticultural soils with mapping, these variables are not directly measured but can be estimated by different mathematical algorithms that were developed for the cartography of Basic Terroir Units (BTUs) (Morlat *et al.*, 2001). The knowledge of these ecophysiological variables can be used to build decision aid maps to help winegrowers to better adjust their agro-viticultural practices to each BTU (rootstock and variety choice, suggested agro-viticultural practices). The rootstock type (Koundouras *et al.*, 2008) and the soil management practices (Barbeau *et al.*, 2006) can also have a significant influence on the vigor of a plot. In a 'low vigor' vineyard, vines have thin and short shoots with few and small leaves. Conversely, a 'high vigor' vineyard tends to induce a rapid shoot growth in spring which may be extended late into the growing season, often after veraison. Since the balance between vegetative growth and reproductive phase influences berry composition, this interaction must be controlled (Carbonneau *et al.*, 2007).

The algorithm, previously proposed by Morlat (2001) to estimate the vigor potential conferred by soil (VIPOS) for each BTU, was calculated from data coming from soil auger observations and soil samples. It was estimated from three variables: 1. Water holding capacity (WHC); 2. Gravel percentage on soil profile (GP), and 3. Parent rock hardness (PAROH). Its estimation was based on an equation and the continuous variables were partitioned into three crisp classes. Most of the time, VIPOS estimation needed to be reevaluated by expertise because of the sharp transition between classes. The objective of the paper is to present a new method to eliminate the problem of the sharp transition due to class bounds. We propose an original method combining statistical analyses and expert evaluation to estimate the VIPOS using a fuzzy inference system. The fuzzy inference system allows i) translating in simple words the relations between the variables and ii) a progressive transition between two classes. Furthermore, this method, despite using uncertain data, provides satisfactory results.

MATERIALS AND METHODS

First algorithm to calculate VIPOS: It was based on an equation where weights were attributed to each variable and class of variables, according to their influence on the vigor potential conferred by soil. A linguistic term was attributed according to the weighted sum of the previous ratings (Figure 1). Gravel Percentage on soil profile (GP) and Water Holding Capacity (WHC) were continuous variables. GP was visually evaluated during soil mapping and depended on auger observations. WHC was a composite variable determined from soil water content at field capacity and wilting point, soil texture, rooting depth and bulk density (Goulet *et al.*, 2004). These two variables were partitioned into three crisp classes by expertise. PAROH was determined according to the parent-rock and deep horizon types (Tab. 1)

Variable	Coefficient	Class	Rating
Gravel percentage on soil profile (GP)	1	> 40% 20 à 40% <20%	1 2 3
Parent rock hardness (PAROH)	1	Hard Soft Crumbly	1 2 3
Water holding capacity (WHC)	2	[0 to 50[mm [50 to 100[mm ≥ 100 mm	1 2 3
→	**VIPOS**	**[4 - 7[** **[7 - 10[** **[10 - 12[**	**Low** **Medium** **High**

Figure 1 : First algorithm proposed by Morlat (2001) to evaluate the vine vigor potential conferred by soil

Table 1: PAROH classes determined according to parent-rock and horizon deep types, pedological nomenclature according to (Baize *et al.*, 2008).

PAROH classes	Pedological nomenclature	Description	Examples
Hard	R	Hard rock formation	Rhyolite
Soft	Rt and C	Soft rock formation and C horizon, altered rock by weathering	Chalk, friable rock
Crumbly	Rm and S	Incoherent rock, structural horizon and alterite formation	Sand, bottomland

Nevertheless, final VIPOS estimation had to be reevaluated by expertise because of the sharp transition between classes. Thus, we wanted to improve the VIPOS evaluation using a new method.

New method to enhance VIPOS estimation using a fuzzy expert system: Fuzzy set theory allows to define the “degree of membership” of an element in a set by means of a membership function. For classical or “crisp” sets, the membership function only takes two values: 0 (non-membership) and 1 (membership). In fuzzy sets the membership function can take any value from the interval [0,1]. The value 0 represents complete non-membership, the value 1 represents complete membership, and values in between are used to represent partial membership (Van der Werf, H. M. G. and Zimmer C., 1998). Firstly, for each input variables (WHC, GP and PAROH) we defined two fuzzy sets: low/high to GP and WHC variables and

Hard/Crumbly to PAROH. Variables were partitioned thanks to k-means statistical analysis or "expert" knowledge of the working-team who did the auger observations. According to input data distribution, k-means analysis generates clusters as distinct as possible. That way, each value of a variable can be characterized by a membership function to the fuzzy sets. The output VIPOS is a continuous variable between 1 (low vigor) and 3 (high vigor).

Secondly, the first algorithm was translated into fuzzy decision rules that consisted of three premises parts (*if…*) linked by *and*, followed by a conclusion (*then…*). Relationships between inputs (WHC, GP and PAROH) and the output (VIPOS) were designed in a fuzzy rule set. We used Sugeno's inference method: a typical rule in a Sugeno fuzzy model has the form *'If input 1 = x and input 2 = y then Output is z = ax+by+c'*. Each rule uses the combination of the input membership values as weighting factors to determine its matching degree with a given sample. The final inferred VIPOS is the weighted sum of all the rule conclusions.

Finally, having thus defined the membership functions and formulated the decision rules, we calculated values of VIPOS. An analysis of sensitivity was conducted to illustrate the system behavior and to validated by expertise the new original method to estimate VIPOS.

Data set and software used: Data came from to the soil characterization of 3847 plots located in the Loire Valley vineyard, France. Statistical descriptive analyses of the dataset were done using the R.2.10.1 software. The fuzzy expert system was implemented through the use of the software program Fispro 3.2 (Guillaume *et al.*, 2002).

RESULTS AND DISCUSSION

Characterization of the three input variables: WHC varied between 10mm and 459mm, GP between 0% and 66% and the three types of parent rock hardness were represented (cf. Table 2). The training data variability allowed this indicator to be used in a wide range of situations.

Table 2: Statistical descriptive analysis of the three input variables: Water Holding Capacity (WHC), Gravel percentage (GP) and Parent Rock Hardness (PAROH).

	WHC: Water Holding Capacity (mm)	GP: Gravel percentage (%)
Minimum	10	0
1st Quartile	65	6
Median	113	11
Mean	124	15
3rd Quartile	154	19
Maximum	459	66

	PAROH: Parent Rock Hardness (% of each type)
Crumbly	34%
Soft	22%
Hard	44%

Selection of the fuzzy partitions for the three input variables: It was difficult to determine the Gravel percentage breakpoints by expertise so we determined the limits of partitions (10% and 40%) thanks to a k-means analysis. There were only three values of parent rock hardness type so this variable was partitioned as a regular grid from 1 'crumbly' to 3 'hard', the 'soft' class was equivalent to the intersection point and therefore was built by interpolation between classes 1 and 3. The two breakpoints 50 and 100mm of water holding capacity were fixed according to expertise. Zufferey and Murisier observe that plots with a WHC below 100mm are sensitive to water stress (Zufferey and Murisier, 2006). The selected fuzzy partitions for each variable are presented on Figure 2.

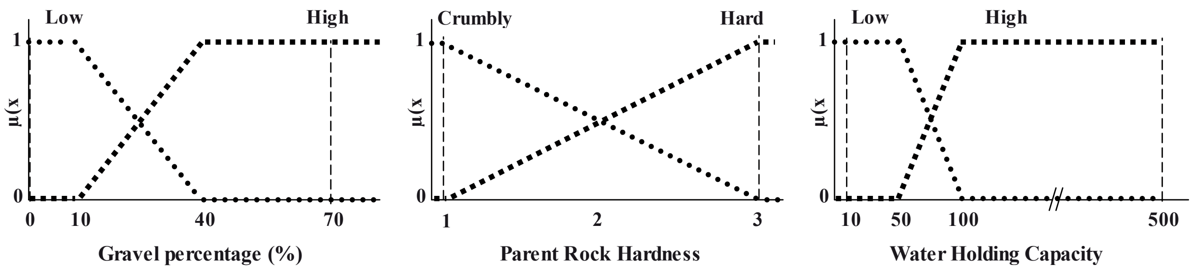

Figure 2: Selected fuzzy partitions for Water Holding Capacity (WHC), Gravel percentage (GP) and Parent Rock Hardness (PAROH) variables, $\mu_{(x)}$ normalised membership degree.

Building a set of decision rules: The set of decision rules covered all the situations that may occurred; that corresponded to eight decision rules (Tab. 3). The weight attributed to each variable in the first algorithm according to their influence on VIPOS was preserved. To determine the output value, we attributed a score of 1 when the output class of the variable ended up to a low vigor and a score of 2 when it ended up with a high vigor, and a weighting factor (2) was attributed to WHC. The scale of output values from 4 to 8 was converted back to a scale from 1 (low vigor) to 3 (high vigor) easier to understand (these building steps are indicated in grey on Tab. 3). The weighting from membership degrees were laid on this last scale.

Table 3: Decision rules for estimation of Vine Vigor Potential conferred by soil (VIPOS) from Gravel Percentage (GP), Parent Rock Hardness (PAROH) and Water Holding Capacity (WHC) (building steps are indicated in grey).

If Gravel percentage on soil profile (GP)	***and*** Parent rock hardness (PAROH)	***and*** Water holding capacity (WHC)	***then*** VIPOS value
Low (2)	Hard (1)	Low (2x1=2)	2+1+2=5 ⇨ **1,5**
Low (2)	Hard (1)	High (2x2=4)	2+1+4=7 ⇨ **2,5**
Low (2)	Crumbly (2)	Low (2x1=2)	2+2+2=6 ⇨ **2**
Low (2)	Crumbly (2)	High (2x2=4)	2+2+4=8 ⇨ **3**
High (1)	Hard (1)	Low (2x1=2)	1+1+2=4 ⇨**1**
High (1)	Hard (1)	High (2x2=4)	1+1+4=6 ⇨ **2**
High (1)	Crumbly (2)	Low (2x1=2)	1+2+2=5 ⇨ **1,5**
High (1)	Crumbly (2)	High (2x2=4)	1+2+4=7 ⇨ **2,5**

Sensitivity tests and validation: In order to illustrate the system behavior and to validate the new method, a sensitivity analysis of the VIPOS indicator to variations in the values of its three input variables is presented on Figure 3.

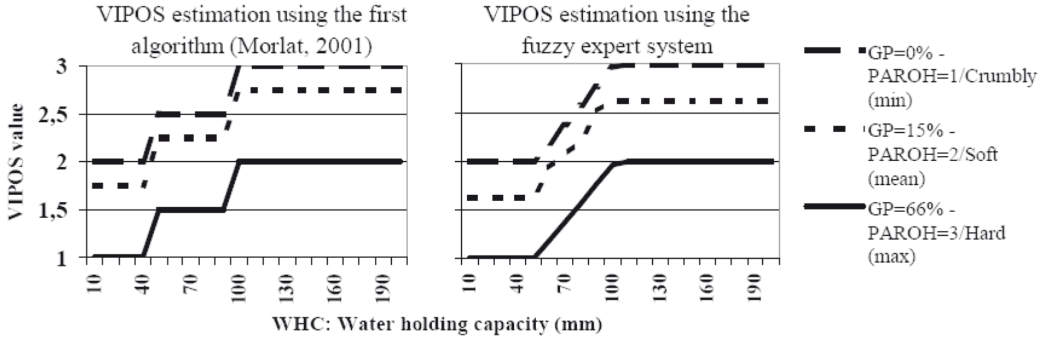

Figure 3: Sensitivity analysis of VIPOS estimation to variations of the input variable WHC (Water Holding Capacity), comparing the former algorithm and the new method. WHC varied from 10 to 200mm while the two other input variables are kept at the minimum, mean or maximum value.

The new method allowed having a continuous estimation of vine vigor conferred by soil and avoided a reclassification through expertise. An example of VIPOS estimation is presented on Table 4. Plot 1 and plot 2 had the same type of parent rock and the same percentage of gravel on the soil profile but had a difference of 40mm water holding capacity between them. In spite of different water holding capacities, using the former algorithm, plot 1 and plot 2 had the same VIPOS value, and need to be reclassified together by hand, with the 1,5 value reset to 2, to better correspond to the reality. With the latter algorithm (fuzzy expert system), the inferred VIPOS values of plot 1 and 2 were respectively 1,1 and 1,9, so the new method avoided the reclassification through expertise. All of the VIPOS estimations can be now completely automatic.

Table 4: Example of VIPOS estimation: comparison between the former algorithm and the latter one, which uses the fuzzy expert system.

			VIPOS estimation using the **former algorithm**	VIPOS estimation using the **fuzzy expert system**
Plot 1	GP=66% - PAROH=3/Hard	WHC=55mm	1,5	1,1
Plot 2		WHC=95mm	1,5	1,9
Plot 3		WHC=100mm	2	2

Two types of validation can be considered: a 'design validation' that evaluates the scientific quality of the indicator construction or design and an 'output validation' that checks the accuracy of the information supplied by the indicator output (Bockstaller and Girardin, 2003). The same authors highlight that indicators are used to assess complex processes that often do not have quantitative equivalents; the estimated indicator can be confronted to measured data but also submitted to expert evaluation. The vine vigor conferred by soil was not measurable, so we choose the expert evaluation. VIPOS indicator will be linked with rootstock, variety and viticultural practices to accurately predict the final vigor of a vine plot. This final vigor is measurable thanks to the pruning weights, for example; once this is done, we will perform a more complete validation.

CONCLUSIONS

This step by step approach using a fuzzy expert system is a very transparent method, because each step can be controlled. The method allows having a continuous estimation of vine vigor conferred by soil and avoids a reclassification through expertise. It also permits to represent the expert knowledge, linking expertise and data mining. On one hand, this approach will be extended to the vine earliness potential conferred by soil and on the other hand the VIPOS indicator will be linked with rootstock, variety and viticultural practices to accurately predict the final vigor of a vine plot.

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