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A New Mathematical Modelling Approach for Viticulture and Winemaking Using Fuzzy Cognitive Maps

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Abstract: The aim of this paper is to present a new approach in modelling wine quality and quantity using Fuzzy Cognitive Maps trained by non linear Hebbian learning algorithm. The methodology described extracts the knowledge from the experts and exploits their experience on wine production. Two case studies with data from real vineyards were examined. The results of this study show that software tools using Fuzzy Cognitive Maps could be explored further and problems that arise during the wine production could be prevented by an efficient decision support system.

Keywords: wine quality, wine quantity, Fuzzy Cognitive Maps, viticulture, winemaking.

1. INTRODUCTION

Over the past ten or so years terms like, green, biodynamic, and biologique have become increasingly popular to characterize vineyards and wineries from California to Bordeaux, from New Zealand to Tuscany and from South Africa to Greece as growers and winemakers have begun paying increasing attention to the impact of their practices on the environment. In addition in California since the late of 2005, the term, sustainable agriculture, has begun to emerge. Today I dare to challenge the scientific community with the term sustainable Viticulture.

Environmental practices have been particularly important all over the world and particularly in California. Over the past 50 years there has been growing tension between agriculture industrial practices that are reluctant to change and urban sprawl, which has taken over much of what was formerly prime farm land. Agricultural practices such as burning, flood irrigation, pesticide spraying, groundwater, air contamination, and other social, economic, and environmental problems have resulted in increased government regulation, which has become an increasing burden on an already languishing agriculture industry.

Partly in reaction to increasing government regulation and partly due to an increased awareness of the agriculture industry's social and environmental responsibility, there has been movement toward sustainable agriculture practices. Sustainable agriculture is characterized by a systems perspective of stewardship of natural and human resources and comprises three goals – environmental health, economic profitability, and social and economic equity. Achieving sustainable agricultural practices is viewed as a process requiring small, realistic, and measurable steps. Due to the peculiarities of specific agriculture sectors, it is very important and necessary to treat every different agriculture sector with special care and attention. Such is the case of viticulture and wine making.

Nowadays wine is increasingly enjoyed by a wider range of consumers. Wine quality is attributed to many different factors of the wine working collectively to bear a sensory experience that is not apparent from considering these components in isolation. The various chemical components in wine give the wine its distinct taste and aroma. Appreciation of wine quality involves moving beyond our innate preferences, (Orth, 2011), (Schamel, 2000).

Certification prevents the illegal adulteration of wines (to safeguard human health) and assures quality for the wine market. Wine certification is often assessed by physicochemical and sensory tests. Physicochemical laboratory tests routinely used to characterise wine include determination of density, alcohol or pH values, while sensory tests rely mainly on human experts. It should be stressed that taste is the least understood of the human senses, thus wine classification is a difficult task. Moreover, the relationships between the physicochemical and sensory analysis are complex and still not fully understood, Orth (2011).

These difficulties could be dealt with the flourishing of new theories and techniques that synergy discipline fields provide such as: Fuzzy Logic, Neural Networks, Neutrosophic, Genetic Algorithms, Probabilistic Reasoning, Soft Computing Techniques, Intelligent Control (IC) and Fuzzy Cognitive Maps (FCM).

In this paper a new mathematical modelling approach of viticulture and winemaking will be implemented in order to check the quality and quantity of the produced wine. Two case studies with data from real vineyards will be examined so as to test our model and simulation results with conclusions will be presented.

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2. BASIC OF VITICULTURE AND WINE MAKING

Wine has been around for a long time since the ancient times. Before water was safe to drink, beverages like wine helped to sustain mankind. In many cases in the ancient times wine was used for medical purposes, which is true even today. Dr. Patrick McGovern, an archeochemist at the University of Pennsylvania observed, with reference to the symposia of ancient Greece, that wine was a beverage that "greased the skids" of Western civilization. Beginning with the hawthorns berries that were used to make a fermented drink nine thousand years ago in China, and continuing with the cultivation of grapes by the Egyptians, Greeks and Romans, wine has formed an integral part of the culinary, religious, and social history of man. We have evidence that the ancient Babylonians and Egyptians practiced viticulture, while the Greeks were the first to conduct a brisk industry and trade in wine. Afterwards the Greeks passed wine to the Romans who in return pushed the grape into France and Germany, thereby planting the seeds of the tradition that is so venerated today. Despite this long history, the fundamentals of winemaking and the plant itself have not changed; wine is still fermented by yeast using grapes of the same botanical origin as those that existed millennia ago. Wine and other alcoholic products always accompanied territorial expansion. History wants William Penn to bring vines with him when he arrived in the New World in 1684. However historically one thing cannot be disputed: viticulture and winemaking was originated on East and mainly in the East Mediterranean regions. Table 1 shows the top 16 wine-producing countries and the total vineyard area in 2011 (Fraga and al. 2012).

Table 1. Top 16 wine-producing countries in 2011 (with respective growth rate from 2007). Total vineyard area in 2011 is also shown (with respective growth rate from 2007).

Country	Wine production (Mhl)/ growth rate		Vine area (mha)/ growth rate	
France	49.6	9%	807	-7%
Italy	41.6	10%	776	-6%
Spain	34.3	-1%	1032	-4%
USA	18.7	-6%	405	2%
Argentina	15.5	3%	218	-4%
China	13.2	6%	560	4%
Australia	11.0	14%	174	0%
Chile	10.6	29%	202	3%
South Africa	9.3	-1%	131	-12%
Portugal	5.9	-2%	240	-3%
Romania	4.7	-11%	204	0%
Brazil	3.5	-1%	92	0%
Greece	2.6	-26%	111	-6%
Hungary	2.4	-24%	65	-13%
New Zealand	2.4	59%	37	21%
Bulgaria	1.3	-29%	73	-22%

We now live in a global age of viticulture and enology, extending from Italy, France, Greece and Germany in the Old World to new regions such as Australia, South America, United States and even in the Far East New Zealand. They all are employing and refining modern viticultural methods that have improved wine quality and contributed to an increasingly competitive marketplace. For example, vertical shoot positioned training has replaced many traditional systems and is now used in almost all of the great winemaking regions. Such shared practices and methods are just one reason why wine is so fascinating. We can now make direct comparisons between Cabernet Sauvignon grown on the left bank in Bordeaux with that grown in Virginia or Napa Valley of USA or Marlborough of New Zealand. Viticulture and enology speak a common language, and wine growers can travel to different countries to talk shop and learn something new. So while the wine industry in the East (its birthplace) is still in its infancy, relatively speaking, it has access to the same knowledge and technology that is being used in the great vineyards of the world. Most vineyards start with a love of wine, and an idea that turns into a passion, but after the light bulb has been switched on … where does one start? Most people who contact the cooperative extension service for advice about grape growing are at the mid-point or near the end of their professional careers, when a vineyard and life as a gentleman farmer as a retirement business or serious hobby looks extremely attractive. A top consultant describes his typical client as "educated, wealthy, ambitious and burned-out." The timeless and irresistible allure of wine is understandable, but the truth to be faced is that if you have come to wine and agriculture later in your life, you will have to overcome immense producing countries in 2011.

3. FUZZY COGNITIVE MAPS-NON LINEAR HEBBIAN LEARNING

The method that will be used in order to model wine production is Fuzzy Cognitive Maps, trained with non linear Hebbian learning algorithm (Anninou and Groumpos, 2014). This algorithm is described by the following steps:

Step 1: Read input state A^0 and initial weight matrix W^0

Step 2: Repeat for each iteration step k

2.1: Calculate A_i according to (1)

$$A_i^{(k+1)} = f(k_2 A_i^{(k)} + k_1 \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} w_{ji}) \quad (1)$$

2.2: Update $W_{ij}^{(k)}$ according to (2)

$$W_{ij}^{(k)} = g \cdot W_{ij}^{(k-1)} + h \cdot A_j^{(k-1)} \cdot (A_i^{(k-1)} - \mathrm{sgn}(W_{ij}) \cdot W_{ij}^{(k-1)} \cdot A_j^{(k-1)}) \quad (2)$$

Step 3: Repeat until the termination conditions are met

Step 4: Return the final weights W^{final} and concept values in convergence region

$A_i^{(k+1)}$ is the value of the concept C_i at the iteration step k+1, $A_i^{(k)}$ is the value of the concept C_j at the iteration step k, W_{ij} is the weight of interconnection from concept C_i to concept C_j and f is the sigmoid function. "k_1" expresses the influence of the interconnected concepts in the configuration of the new value of the concept A_i and k_2 represents the proportion of the contribution of the previous value of the concept in the computation of the new value (Groumpos, 2010),(Groumpos and Stylios, 2000).

The sigmoid function f belongs to the family of squeezing functions, and the following function is usually used to describe it (Papageorgiou, 2013):

$$f = \frac{1}{1+e^{-\lambda x}} \quad (3)$$

This is the unipolar sigmoid function, in which $\lambda>0$ determines the steepness of the continuous function f(x).

The parameter h is the learning rate and g is the weight decay parameter. These parameters ensure that the learning process converges quickly in a desired state.

FCMs lead to the proposed decision making approach following the experts' knowledge strictly (Groumpos and Anninou, 2012), (Runkler, 1997).

4. A FCM FOR WINE MAKING

Weather conditions at any moment act decisively, positive or negative, in the process of growth of the vine and the ripening of the grape and therefore predetermine the quality of wine to be produced. More specifically rainfall rate in conjunction of course with the absorbency of the soil, determines the available water quantities. If these quantities are very small circulation of nutrients within the plant is not possible. But if on the other hand they are extravagant we have quality degradation due to increased production. Rainfalls are necessary in the winter months for stockpiling that will help the plant in dry summer months. Around 27 inches of rainfall throughout the year in order to produce grapes are suitable for winemaking. In ideal circumstances the vine will receive most of the rainfall during the winter and spring months. But a rainfall before the harvest can be fatal, because, due to the wet and warm atmosphere the development of diseases, that also leads to the destruction of production, is favored (Rodo and Comin, 2000). So the concept of "rainfall before the harvest" is necessary for our model.

The harvesting of wine grapes is one of the most crucial steps in the process of winemaking. The time of harvest is determined primarily by the ripeness of the grape as measured by sugar, acid and tannin levels with winemakers basing their decision to pick based on the style of wine they wish to produce. It is based on the physiological and technological maturity of the grapes which is calculated with checks carried out on representative samples of grapes. The early harvest will give us fine wines with low alcohol content while late harvesting would give us wines with high alcohol content and low acidity. The different grape varieties and local and annual weather conditions unavoidably affect the date (Golan and Shalit, 1993).

There are many aspects of grape maturity that determine the best time to harvest wine grapes. Some of these are quantitative and can be determined to a high degree of numerical accuracy, and others are qualitative and are more subjective. There is also a wide variance of maturity time from one varietal to another.

Qualitative indicators of grape maturity include appearance of the grapes including the color and firmness of the skins, the appearance of the stems, the color and taste of the seeds, the taste of the grapes and the condition of the vines and leaves. Current and expected weather conditions also play a role in deciding when to pick.

Quantitative indicators include measurements of the actual chemistry of the grape itself. They include the analysis of pH, and titratable acid (TA). These indicators are useful in determining if a wine is balanced.

Pruning is one of the most important procedures in vineyard. The reasons why to prune are the following:

- Maintain vine form
- Regulate the number and positions of shoots on a vine, and cluster number and size.
- Improve fruit quality and stabilize production over time.
- Improve bud fruitfulness by bud selection and placement.

Pruning of grapevines is recommended anytime after leaf fall, which may occur late fall or throughout the winter. Once the leaves fall, the vascular system becomes inactive and plugs up. Before this time, minerals and carbohydrates are transferred from the leaves into the permanent, woody structures of the vine for winter storage. For this reason, pruning before leaf fall can affect storage leading to mineral deficiencies and poor bud maturation, which can affect the growth of the vine and the crop in the following season. Timing of pruning within the dormant season may also affect the time of bud break. Vines pruned very late in the season usually start spring growth slightly later than those pruned mid-dormancy.

The rest of the concepts are (Clarke and Bakker, 2004):

Soil and vineyard are basic parts of a single chain, which starts in the vineyard and ends in a wine bottle, (Gladstones, 1999). The concept of 'territory' (territoir) is the result of the following three natural parameters: subsoil and the bedrock from which it derives, the topography of the area and the climate that interferes with the evolution of the 'territory'.

The climate of each region is a component of several factors. The main factors are: latitude, average temperatures during the year, altitude, humidity, levels of sunshine and wind, water masses, etc. The climatic conditions prevailing in an area affect the growth of the vine and the quality of wine as well. The cold, the heat, the sun, the rain have a positive or a negative impact on the development of the vine and the maturation of the grapes and thus can predefine the quality of the wine that will be produced. The volume of rainfall in combination of course with the absorbency of the ground and the winds indirectly affect the quality of wine.

The grape variety is one of the most important factors that influence or determine the type, the distinct aroma and the flavor of wine that will be produced. The size of the grape berry, the composition and the color of the crust, the texture, the ratio of sugars and acids etc. depend directly on the genetic traits of each vineyard.

For centuries, vine and man are tied to an interactive relationship, as regards the production of wine. The wine grower can enhance the soil ingredients by applying many cultivation techniques and farming cares, either natural (eg. plowing, pruning) or chemical (eg. annual fertilization, protection from diseases and pests). He can choose the grape variety and also the planting density so it could be suitably adapted to the environment.

The alcoholic fermentation is the conversion process of fresh grape juice into wine and is the most critical point of winemaking. The alcoholic fermentation caused by yeasts (yeast), single-celled organisms that are found in the crust of the grape and have penetrated into the juice. Their main job is to convert the sugars of fresh juice of the grape into alcohol.

The wine may possibly has diseases due to other microorganisms that are aerobic or anaerobic while other alterations of the wine are usually due to a bad winemaking practice.

In an effort to limit the growth of undesirable microorganisms found in the wine and to keep the conduct of the alcoholic fermentation smooth, we use certain additional oenological substances that will help both to produce a qualitative wine and to keep it in good condition.

The storage conditions of wine in the barrel such as its exposure, the material of the barrel, the level of humidity, the temperature, the ventilation provided, the blocking of other odors, the appropriate lighting, etc. significantly affect the quality of the wine.

The maturation-aging of the wine is a great and interesting process, in which many changes in color, smell and taste occur. As long as the wine stays in the cellar, it loses its "harshness" and becomes "soft" in taste, it also loses the smell of "yeast" and acquires a fragrance, which, with the passage of time, becomes more complex.

So we conclude to the following concepts:

C1: The special characteristics of the soil

C2: The climatic conditions in the region's vineyard

C3: The grape variety

C4: The Human Factor (cultivation tasks and farming cares in the vineyard)

C5: The Alcoholic Fermentation

C6: Diseases, alterations and deterioration of the quality of the wine

C7: Additional Oenological Substances to wine

C8: The Storage of wine in barrels

C9: The Maturation - Aging of wine

C10: Rainfall before the Harvest

C11: Time of Harvest

C12: Pruning

C13 (Output): Wine Quality

C14 (Output): Wine Quantity

Experts after assessing and evaluating the relationships between concepts conclude to the Table 2.

A Fuzzy Cognitive Map model is illustrated in Fig. 1.

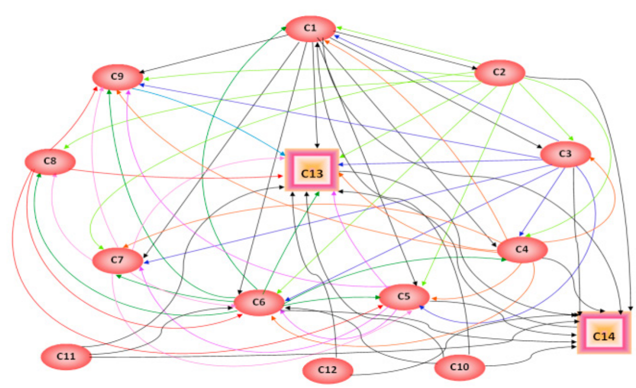

Fig. 1. Fuzzy Cognitive Map Model

5. CASE STUDIES

5.1 First Case

Vineyard in Patras with ideal soil features has climate characteristics for 2014 shown in the following figures (Anon, 2015):

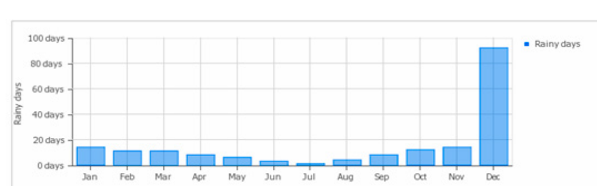

Fig. 2. Rainy Days in Patras.

Table 2. Linguistic Variables describing the relationships between concepts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	-	W	VS	M	M	M	M	-	M	-	-	-	VS	S
C2	S0	-	S	VS	S	S	W	M	M	-	-	-	VS	S
C3	W	-	-	W	S	M	M	W	S	-	-	-	VS	S
C4	W	-	M	-	M	S	M	-	W	-	-	-	VS	S
C5	-	-	-	-	-	W	M	-	W	-	-	-	S	S
C6	-	-	-	W	S	-	VS	W	M	-	-	-	S	VS
C7	-	-	-	-	S	S	-	M	S	-	-	-	S	-
C8	-	-	-	-	W	M	-	-	S	-	-	-	VS	-
C9	-	-	-	-	-	-	-	-	-	-	-	-	VS	-
C10	W	-	-	-	-	M	-	-	-	-	-	-	VS	VS
C11	-	-	-	-	-	M	-	-	-	-	-	-	VS	VS
C12	-	-	-	-	-	-	-	-	-	-	-	-	VS	VS
C13	-	-	-	-	-	-	-	-	-	-	-	-	-	-H
C14	-	-	-	-	-	-	-	-	-	-	-	-	-H	-

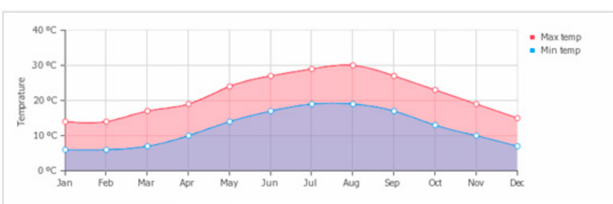

Fig. 3. Min and Max Temperatures in Patras.

The grape variety is Roditis which is a rose colored grape. The time of harvest is by the end of September and pruning was implemented in March.

By using these information to extract the initial values of input concepts, we conclude to the simulation results illustrated in the next figure:

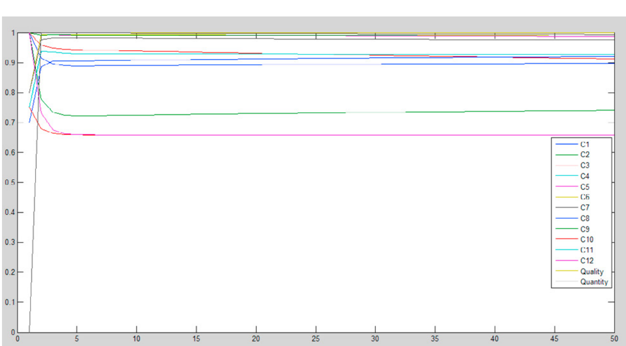

Fig. 4. Simulation Results till Convergence.

With these almost perfect conditions the quality and quantity of the wine (C13, C14) are the best. Both values of these two concepts are over 0.9. That means that there is no doubt that by following these conditions the results of the produced wine would be the best possible. This result is validated by the statistics of Achaia Clauss, a Greek winery located in Patras, in Peloponnese.

5.2 Second Case

In 2014 wine producers in Italy faced their worst grape harvest for more than half a century due to an unusually wet spring and summer. Thus we will examine Puglia, where the production was reduced up to 30% that year.

That year's harvest started later than usual because of the poor weather and continued until late October. So concepts C10 and C11 were most affected.

By examining the growth conditions of Bombino Bianco and implementing them in order to validate the production, indeed the wine quality and quantity were influenced.

Simulation results are illustrated in Fig. 5

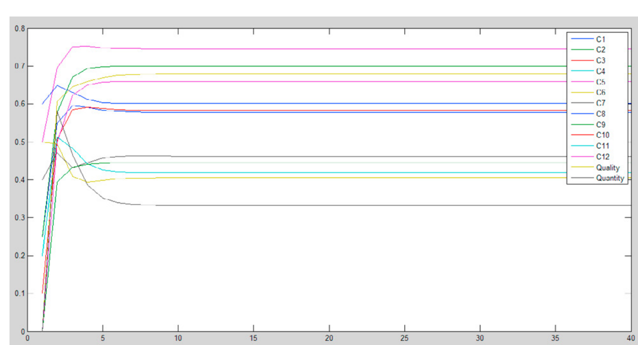

Fig. 5. Simulation Results till Convergence

In that case quantity is affected most as its value is the lowest in the equilibrium point (C14= 0.3320). That ensures that quantity will be limited with the specific data. As far as quality is concerned it is not so affected

(C13=0.68) so that means that the quality in that year's production is satisfactory.

6. CONCLUSIONS

In this paper, the mathematical theories and tools of FCM, developed previously, have been used to theoretically model the wine quality and quantity. The proposed model provides a total new approach which is clear, simple, user-friendly, real time, easily accessible, fast, reliable and of low-cost. In addition the aforementioned software tool can support the laboratories to have on their desk a first evaluation of the wine that they are going to inspect.

The interesting results obtained here show new and promising future research areas. More simulations are necessary in order to ensure the good wine production.

7. ACKNOWLEDGMENTS

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REFERENCES

Anninou, A. and Groumpos, P. (2014). Modeling of Parkinson's Disease Using Fuzzy Cognitive Maps and Non-Linear Hebbian Learning. *International Journal on Artificial Intelligence Tools*, 23(05), p.1450010.

Anon, (2015). [online] Available at: Weather-and-climate.com, 'Weather and Climate: Patras, Greece, average monthly, Rainfall (millimeter), Sunshine, Temperatures (celsius), Sunshine, Humidity, Water Temperature, Wind Speed', 2015. [Online]. Available: http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Patras,Greece. [Accessed 31 Jul. 2015].

Clarke, R. and Bakker, J. (2004). *Wine flavour chemistry*. Oxford, UK: Blackwell Pub.

Fraga, H., Malheiro, A., Moutinho-Pereira, J. and Santos, J. (2012). An overview of climate change impacts on European viticulture. *Food Energy Secur*, 1(2), pp.94-110.

Gladstones, J. (1999). *Viticulture and environment*. Adelaide: Winetitles.

Golan, A. and Shalit, H. (1993). Wine Quality Differentials in Hedonic Grape Pricing. *Journal of Agricultural Economics*, 44(2), pp.311-321.

Groumpos, P. (2010). Fuzzy Cognitive Maps: Basic Theories and their Application to Complex Systems. In: M. Glykas, ed., *Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications.*, 4th ed. Heidelberg: Springer-Verlag Berlin, pp.1-22.

Groumpos, P. and Anninou, A. (2012). A theoretical mathematical modeling of Parkinson's disease using Fuzzy Cognitive Maps. In: *International Conference on Bioinformatics and Bioengineering (BIBE 2012)*. pp.677-682.

Groumpos, P. and Stylios, C. (2000). Modelling supervisory control systems using fuzzy cognitive maps. *Chaos, Solitons & Fractals*, 11(1-3), pp.329-336.

Orth, U. (2001). Quality signals in wine marketing: the role of exhibition awards. *The International Food and Agribusiness Management Review*, 4(4), pp.385-397.

Papageorgiou, E. (2013) *Fuzzy cognitive maps for applied sciences and engineering*.

Rodo, X. and Comin, F. (2000). Links between large-scale anomalies, rainfall and wine quality in the Iberian Peninsula during the last three decades. *Global Change Biol*, 6(3), pp.267-273.

Runkler, T. (1997). Selection of appropriate defuzzification methods using application specific properties. *IEEE Trans. Fuzzy Syst.*, 5(1), pp.72-79.

Schamel, G. (2000). *Individual and collective reputation indicators of wine quality*. Adelaide: Centre for International Economic Studies.