A PROCEDURE FOR THE ZONING OF GRAPEVINE IN A HILLY AREA (COLLIO, NORTH-EASTERN ITALY) USING SIMULATION MODELS AND GIS

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Abstract

The zoning of grapevine in a hilly area should consider the variability of the environmental characteristics due to topography. Since soil and climate data are usually available as point data, reliable spatialization procedures need to be developed, mainly based on topography.

For a hilly area of about 7000 ha (including 5000 ha of the Registered Origin Denomination "Collio") in Friuli-Venezia Giulia region, North-Eastern Italy, information was integrated from meteo stations, soil survey, geology and topography (coded in a Digital Elevation Model), using a GIS (Idrisi 2.0), a deterministic model of the cropping system (CSS, Cropping System Simulator) and a stochastic weather generator (Climak). CSS and Climak were developed at the University of Udine.

A procedure was developed for the spatialization of soil and climate parameters, starting from point data and using ancillary information mainly about topography. The area was then divided in homogeneous units (given by a unique combination of soil and climate conditions) on which the CSS model was run, obtaining data on potential yield for each unit and yield shortage due to possible water stress.

A field survey was carried out, focusing on the relationship between grape characteristics (yield, sugar concentration at harvest) and soil, climate, topography, cultivation management techniques and crop features.

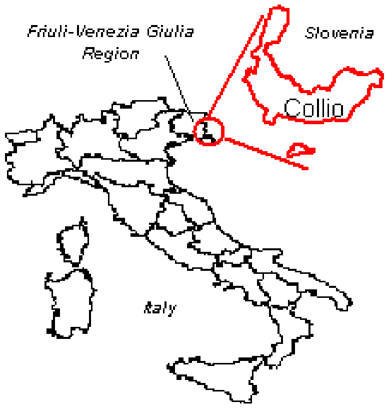
The evaluation of land suitability for grapevine cultivation was based on 1) expected quality of production, as a function of aspect, Huglin's heliothermal index and yield reduction in non irrigated vineyards due to water stress (the most limiting factor); 2) potential suitability for grapevine, depending on quality and yield productivity in non irrigated vines; 3) actual suitability for grapevine, obtained combining potential vocation and ease of cultivation (as a function of slope).

A multi-criteria procedure allowed to define 4 classes of land suitability for grapevine cultivation, described as 'not suitable', 'poorly suitable because of high transformation costs', 'suitable' and 'very suitable'.

1. Introduction

The zoning procedures to determine the cultural attitude of land have been studied in several researches, both on grapevines and other crops (Castonguay, 1985).

Vineyard is a complex system whose production's quality and quantity derive from the interaction among soil, climate, orography, variety/rootstock and cultivation techniques. In hilly areas, the orography effect is particularly relevant; therefore in such areas the zoning of grapevine should start considering the variability of the environmental characteristics due to topography. Furthermore, orography can be used for its own relevance and also as an independent variable which can help to spatialize data as soil and climate, usually available as point data.



1.1. The study area

This study was performed on a hilly area of about 7000 ha (including 5000 ha of the Registered Origin Denomination "Collio") in Friuli-Venezia Giulia region, North-Eastern Italy. In this area, 1370 ha of vineyards are planted, pertaining to 7 Municipalities. This area is world-wide recognized as one of the best areas for high quality white wines but also very good red wines are produced here.

Many areas are characterized by steep slope, which makes the agronomic exploitation difficult. The irrigation is generally not used, except for some areas where aid irrigation is applied to balance the effects of severe water stress and improve the quality and quantity of grapes.

1.2. Aim of the research

The aim of this research was to characterize the territory on the base of physical data (soil, climate, topography) to define its suitability for grapevine cultivation and create a map of agronomic suitability for this crop. This map should help local administrations in defining the guidelines for land use planning and for a further development of viticulture in the area. Another goal is to supply decision support elements based on the possibility/difficulty to change the actual land use (defined in the General Plans) to be more consistent with the agronomic suitability (Fregoni *et al.*, 1992; Falcetti *et al.*, 1997; Parodi, 1997) (Map of the inertia in changing the actual land use).

2. Materials and methods

2.1. Input data

The variables that should be considered in a zoning procedure are: production (quantity and quality), sensitivity to infections and diseases, climate, geology, soil, topography, social and economic aspects, roads and land use restrictions.

In this first approach, the data used were: data from meteo stations, soil pedological characteristics, geological map, topographical data (altitude, aspect and slope derived from a Digital Elevation Model). The other parameters will be used in a further study. These data were processed using a GIS (Idrisi 2.0), a deterministic model of the cropping system (CSS, Cropping System Simulator) and a stochastic weather generator (Climak), both developed at the University of Udine (Danuso, 1996; Danuso *et al.*, 1999; Danuso and Della Mea, 1994).

Other data used in this research have been: the General Plan of every Municipal District with the details on land use, hydro-geological restrictions, environmental restriction.

A field survey was carried out, to record data on the relationship between grape characteristics (yield, sugar concentration at harvest) and soil, climate, topography, cultivation management techniques for different cultivars grown in the area.

2.2. Spatialization of point data

The map of altitude (Digital Elevation Model, DEM) was obtained through interpolation of elevation point data, extracted by the digital maps provided by the Region Friuli-Venezia Giulia (scale 1:5.000). In order to have tasseled data (soil and climate data) for all the sites of the area, a procedure was developed for the spatialization of soil and climate parameters, starting from point data and using the DEM data.

2.2.1. Digital Elevation Model

The DEM was obtained using the raster GIS Grassland (LAS Inc., 1996), with cell size of 10 m (1755x1795 cells). The interpolation algorithm was the inverse of distance mean weight. The DEM was then imported in the Idrisi GIS (Idrisi, 1995), that was used for the further data processing, including the calculation of slope and aspect maps.

2.2.2. Soil

The soil survey was performed with field data collection based on a *landscape map*, obtained combining the geological map, slope map, aspect map and aerial photographs.

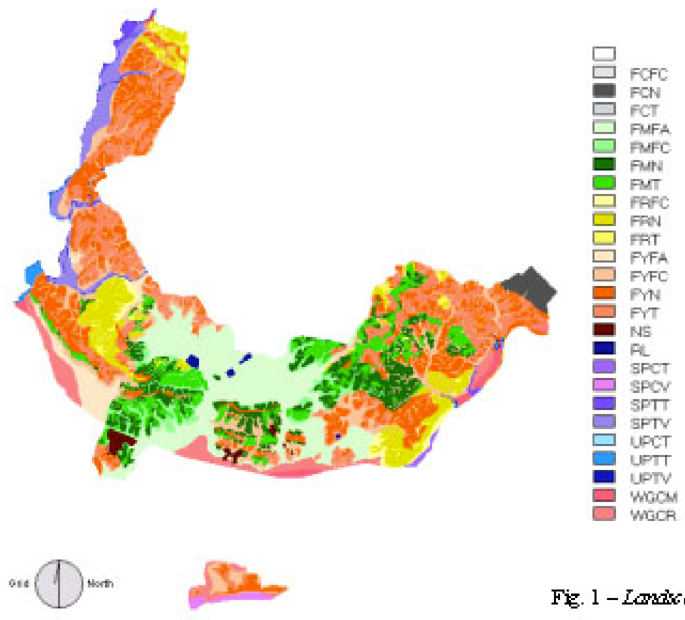


Fig. 1 – *Landscape map and soil test sites*

The landscape map contains 25 *landscape units* (see Fig. 1).

A manual drill (1.2 m height) was used to collect 155 soil samples. For every horizon the following parameters were recorded: colour, texture, gravel, pH, HCl reactivity, illuvial concretions. On 40 samples, more detailed chemical, physical and hydrological analyses were performed on the upper horizon. Every soil sample was classified according to the soil taxonomy classification system WRB - World Reference Base for soil resources (FAO, 1998)

The hydrological characteristics (measured for 40 sites) were extended to all the 155 sites by a multiple regression model developed on the basis of texture and organic matter.

The spatialization of soil parameters to the whole area was performed assigning to every unit of the landscape map (25) the mean value of the samples belonging to that unit.

2.2.3 Climate

The meteo input data were recorded in 15 meteorological stations from 1990 to 1998. These data were used as input in the stochastic weather generator Climak (Danuso and Della Mea, 1994), obtaining a set a 148 parameters describing the climate for every station. From these parameters, Climak can generate weather data to perform Monte Carlo simulations. Moreover, these parameters can be spatializaed more easily than the original data. Only 11 among the 148 parameters were found to vary depending on the variables known for each cell. These 11 climate parameters were then extended to every cell of the whole area (27988 square cells, with definition of 50 m) by means of multiple regressions based on altitude and aspect. The result of these calculation was a database of 27988 cells x 11 variables. On this database, the Principal Component Analysis was performed, followed by the Cluster Analysis on the first 3 axes of the PCA, grouping the cells in 8 classes (Fig. 2).

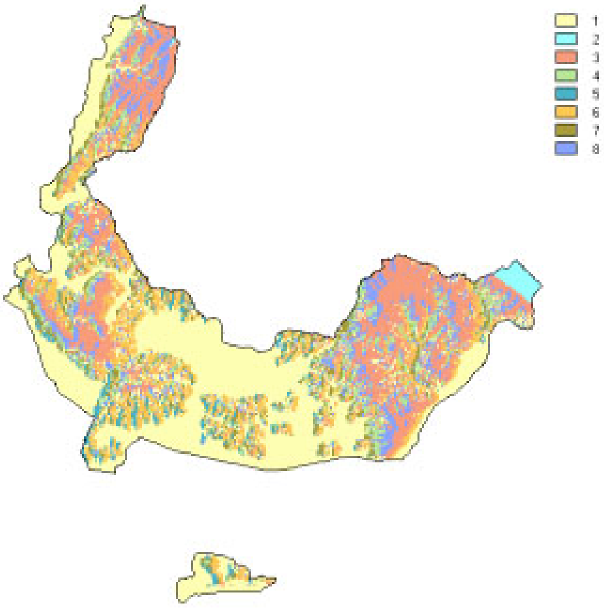


Fig. 2 – *Meteo classes*

For every meteo class, 50 years of climatic data were generated with Climak; these data were used to calculate the Huglin's index (Huglin, 1978) and to run the CSS model.

2.3. Use of the cropping system simulation model

A Cropping System Simulator (CSS) was used to evaluate the productivity of vineyards without irrigation (rainfed conditions). The reason for this choice (using a model instead of historical data) is that historical data are often not complete or not reliable and they are influenced by specific management and cultivation techniques. Moreover, historical data are collected at point sites and they are not available for the whole surface.

CSS is a collection of interconnected modules that simulate the dynamics of the soil and crop system and their interactions with the environment. CSS modules simulate crop phenology, crop biomass production, reduction of potential yield depending on water and nitrogen deficiency and soil dynamics of water, nitrogen, phosphorous, organic matter, crop residues and herbicides. CSS works with daily time step for calculations, input variables and simulation results. For this study, only the crop and water modules were employed. The CSS model was adapted for grapevine and for the specific characteristics of the Region Friuli-Venezia Giulia.

The study area was divided into 145 homogeneous units (given by a unique combination of a soil unit and a climate class) on which the CSS model was run, with the input of 50 years of daily meteorological data (temperature, rainfall and reference evapotranspiration) generated with Climak for every meteo class. The 50-year run can be considered a "Monte Carlo" simulation, where a deterministic model is used with a stochastic input: the climatic variability propagates in the model and generates variable results which, therefore, show a probability distribution.

The total number of simulations (50 years x 145 units) was of 7250.

The simulations produced data on potential yield for each unit and yield shortage due to possible water stress.

2.4. The procedure for agronomic evaluation

The land suitability for grapevine cultivation was evaluated through a multi-criteria and multi-step procedure (fig. 1) based on

1. *expected quality of production (good grapes for high quality wines)*. In this research, the parameter used to estimate the quality of grapes was sugar concentration as a good indicator of global quality and for its ease of determination. Quality is as a function of aspect, Huglin's heliothermal index and yield reduction in non irrigated vineyards due to water stress (the most limiting factor in this area, particularly on steep slopes);

2. *potential suitability for grapevine*, depending on quality and yield productivity in non irrigated vines: the higher yield and quality, the higher the potential suitability;

3. *actual suitability for grapevine*, obtained combining potential suitability and ease of cultivation (as a function of slope): the higher the slope, the lower the ease of cultivation and therefore the actual suitability.

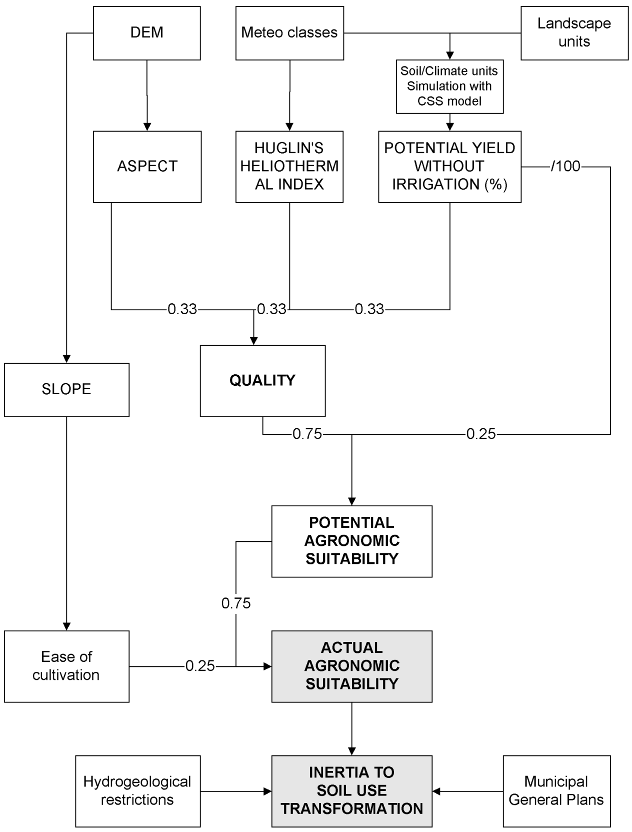


Fig. 3 — *The procedure for agronomic evaluation*

Prior to their combination with the weights reported in Fig. 3, the variables were normalized from 0 to 1 according to the following relationships.

Relationship Aspect-Quality

Aspect	**NE**	**SE**	**SW**	**NW**	**plain**

Normalized variable	0.7	0.9	1.0	0.7	0.7

Relationship Huglin's Heliothermal Index-Quality

Huglin's Heliothermal Index	**<2100**	**2100-2150**	**>2150**
Normalized variable	0.8	0.9	1

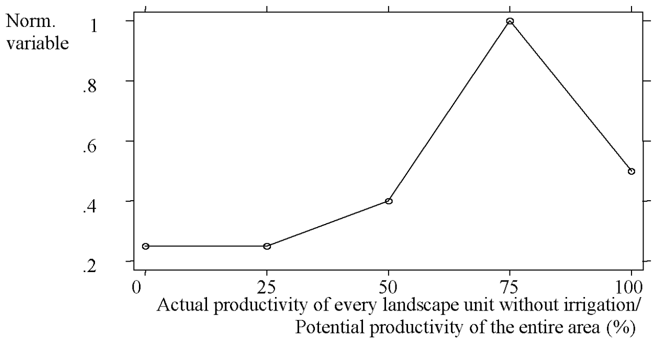


Fig. 4 - *Relationship Percentage of actual productivity without irrigation-Quality*

The expected quality of production derived from the average of the normalized variables calculated from aspect, Huglin's index and percentage of actual productivity without irrigation.

Relationship Percentage of actual productivity without irrigation - Potential suitability for grapevine: The normalized variable is calculated dividing the original variable (percentage) by 100.

The Potential suitability for grapevine is calculated as a sum of normalized productivity x 0.25 and quality x 0.75.

Relationship Ease of cultivation - Actual suitability for grapevine

Slope %	**0-5**	**5-20**	**20-35**	**35-50**	**>50**
Ease of cultivation	1.0	1.0	0.9	0.6	0

The area with slope exceeding 50% were excluded, for being too difficult to be cultivated.

The Actual suitability for grapevine is calculated as a sum of Ease of cultivation x 0.25 and Potential suitability x 0.75.

3. Results

The multi-criteria procedure allowed to define 5 classes of land suitability for grapevine cultivation, described as 'not suitable', 'poorly suitable because of high transformation costs', 'fairly suitable, low transformation costs', 'suitable' and 'very suitable' (see Tab. 1, Fig. 5).

Tab. 1 — Classes of Agronomic suitability for grapevine cultivation

Classes	Actual suitability	Slope
1. Not suitable for excessive slope	-	>50%
2. Poorly suitable because of high transformation costs	<0.8	35-50%
3. Fairly suitable, low transformation costs	<0.8	-
4. Suitable	0.8-0.86	-
5. Very suitable	>0.86	-

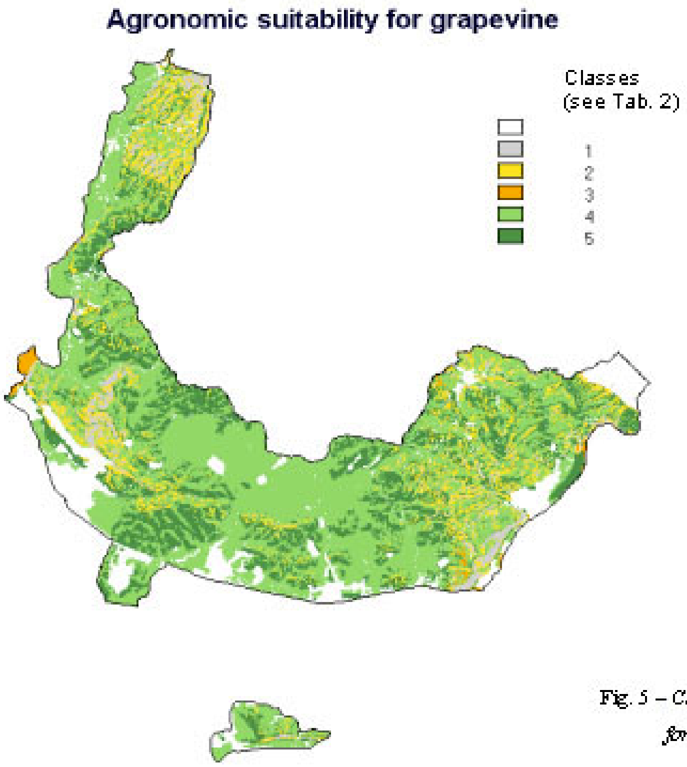


Fig. 5 – Classe of agronomic suitability for grapevine cultivation

The agronomic suitability map was combined with the map of actual land use (General Plans). The result was an evaluation of the actual use (if it is consistent or not with the agronomic suitability); an evaluation of the inertia to land use change was also performed.

The inertia to the change is high where the consistency of agronomic suitability and actual land use is high; the inertia is also high where there are strong restrictions to the change (e.g. hydrogeological or environmental restrictions). On the other hand, the inertia is low where the agronomic suitability and actual use differ substantially and there are no or little restrictions to the change.

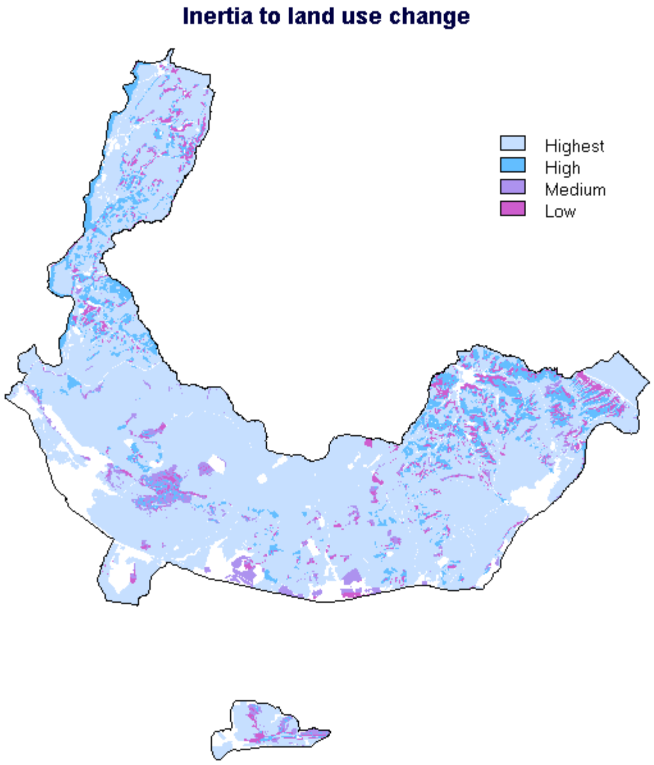


Fig. 6 — *Inertia to land use change*

4. Conclusions

This study is a first approach of a wider integrated survey of the Collio area to define its suitability for grapevine cultivation. The overall impression is that the actual land use is, in the majority of sites, substantially correct. Only in a minor percentage of the area (about 8% of the total cases) the inertia to land use change is low or medium. Nevertheless, if this surface (about 500 ha) would be planted with vineyards, this could be a positive increase of the viticultural and enological economy of this area.

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