OPTIMIZING VINEYARD IRRIGATION THROUGH THE AUTOMATIC RESISTIVITY PROFILING (ARP) TECHNOLOGY. THE PROPOSAL OF A METHODOLOGICAL APPROACH

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ABSTRACT

In Tuscany, central Italy, grape cultivation and wine production (i.e., Chianti DOCG, Brunello di Montalcino) are farming activities appreciated worldwide.

Differently from the past, irrigation is allowed to meet the intense physiological stress that may occur during seasons affected by the increasing climate variability, in order to guarantee quality product and hence high market profitability in many vine areas.

Most vineyards are located in fields along sloping hillsides, where ground slopes and soil characteristics may vary greatly within the same cultivated area. Such situation requires well designed and assembled micro irrigation systems, as well as proper irrigation management due to the three dimensional spatial variability of soil hydrological characteristics.

Water supply according to the variable rate application (VRA) approach, typical of precision farming, requires that both system performance and soils properties are well known, since they affect the application efficiency (AE) of irrigation water.

Soil characterization, in space and depth, is allowed by different approaches. Sampling carried out according to statistical distribution methods is time and resource consuming. In order to get similar or better accuracy with minimal soil samples, the Automatic Resistivity Profiling (ARP) technology can be profitably used. ARP allows rapid surveys of the spatial distribution of different soil layers, namely the vine active root zone profile, through the Soil Electric Resistivity (SER) properties. Supported by GPS technology, 30,000 measured values per hectare are provided. Resistivity maps referred to different layers (i.e., from 0 to 170 cm) are yielded by the ARP technology. Since SER is related to the clay content, maps of clay distribution within the field can be supplied in real time. Field splitting according to in-field resistivity variations can help the assessment of soil sampling sites.

The settlement of irrigation sectors or other tricks able to match high AE can be arranged, affecting seasonal water and energy use as a consequence.

Keywords: Precision agriculture, site-specific irrigation, Automatic Resistivity Profiling.

INTRODUCTION

In the past, crop irrigation requirements did not consider limitations of the available water supplies. Increasing municipal and industrial demands for water, are necessitating major changes in irrigation management and scheduling in order to increase the use efficiency of water that is allocated to agriculture. Moreover, due to the climatic change, mean summer temperature increases and precipitations decrease during the same period, resulting in increased ET demand and reduced water availability (Caretti, 2009). Several agronomic measures aiming to increase grape characteristics can help the demand management for irrigation water, as well as modern irrigation facilities and design support tools. Modern vineyard irrigation do not only support grape production and quality management, but can also reduce or avoid the detrimental effect of water stress following harvest, this condition having the potential for reduced root growth and nutritional deficiencies during the following spring (Grimes & Williams, 1990). Careful water management can influence roots distribution, and it is recognized as a tool for achieving some control of grapevine growth and development. Tuscany, central Italy, yields typical wines, such as Chianti, Nobile di Montepulciano, Vernaccia di San Gimignano and Brunello di Montalcino, appreciated worldwide. Tuscan viticulture, from grape cultivation to wine production, is subjected to severe regulations concerning yields and inputs application. At farm level, the current attitude is towards the precise supply of production resources, in the general framework of farming economy according to the approach of precision viticulture. Such attitude is becoming substantial in the typical wine-growing areas of Tuscany, characterized by appreciable ground slopes, in-field soil heterogeneity, and vulnerable environments.

VINEYARD IRRIGATION

Where the problem is vine water stress, and irrigation water is available, the question is one of economics associated with the installation of an appropriate irrigation system and the expected improvement in vine growth and productivity. Depending upon when and why the stress occurs, soil and site characteristics, and grape variety, the decision to irrigate and the choice of irrigation system will vary significantly. Most of published research on irrigation strategies, carried out in Australia, South America, South Africa and United States on several varieties, demonstrates the effectiveness of proper irrigation management on water saving, wine quality and economic return. In Italy, introduction of vine irrigation was hampered by cultural reasons. Up to now, limited research activity was dedicated to vine irrigation in the typical hilly wine-growing lands of Tuscany. Despite irrigation could be needed to ensure grape production and vineyard value in these areas, lack of detailed information about the variability of soil properties and the spatial distribution of crop vigour may affect the irrigation process (Al-Karadsheh *et al.* 2002), especially in areas characterized by steep slopes.

Today, great potential is expected by irrigation technologies and irrigation management practices (i.e., scientific irrigation scheduling). In spite of this, irrigation inefficiency is the rule rather than the exception. Efficient water use can be increased when water is applied accounting for the spatially distributed crop water demand, a basic principle supporting precision irrigation. In-field variations of crop water demand mainly depend on variability of soil properties and topography. This condition affects many valued Tuscan vineyards located in sloping hilly areas.

NEW TOOLS FOR INTEGRATED SOIL PROFILING

In-field soil variation is a typical condition of Tuscan viticulture. Assessment of soil characteristics aims to determine the soil parameters affecting grape quality, the maintenance of a suitable rooting environment, and to provide possible physical and chemical measures.

Moreover, many field surveys demonstrated that in-field soil variability affects the spatial distribution of crop vegetative development, particularly leaves and canopy expansion (Proffitt *et al.* 2006). The search for new technological tools able to assess such variability, is becoming of paramount importance in precision viticulture.

Today, the application of new integrated survey methods for the implementation of high-resolution soil mapping allows to provide practical support to specific needs of quality viticulture, such as:

- how and where to realize water regulating works, respecting soil and landscape constraints;
- how and where to realize a drainage network on the basis of cost per linear meter;
- assessment of soil movements convenience and selection of appropriate machinery;
- selection and design of irrigation systems allowing in-field diversification of vineyard water supply according to the Variable Rate Application (VRA) approach.

Traditional soil survey, supported by in-field geo-referenced sampling, is carried out by destroying the soil samples. Together with the drilling investigation, innovative tools for non-destructive soil monitoring have been produced in recent years. The spatial distribution of soil variability can be evaluated, providing increased accuracy to both field and laboratory data.

GPS and GIS software are becoming fundamental tools in both doing multilevel analysis of investigated parameters and getting a comprehensive evaluation of the different vineyard characteristics according to the final goals. On the other hand, it is important to underline that the new survey methodologies can just support the traditional soil sampling, since they cannot be alternative in getting precise hydrological information (Pagni *et al.* 2008).

Electromagnetic induction sensors (EMI sensors), ground penetrating radar (GPR) and geo-resistivimeter are the most effective tools for soil and agronomic applied studies (Hezarjaribi and Sourell, 2007). Geo-positioned soil data allowed by integrated GPS systems, can be analyzed under high spatial resolution and yield specific maps that can be overlapped with other thematic layers (i.e., vine vigour, digital elevation model, agro-phenologic data).

THE AUTOMATIC RESISTIVITY PROFILING METHODOLOGY

One of the current methods for integrated soil analysis is characterized by the combination of traditional techniques and continuous measurement of electrical soil resistivity, at three different depths, trough the Automatic

Resistivity Profiling (ARP) technique. The geo-electrical method is based on the measurement of the soil electrical resistivity, given by the measured potential drop of an electric impulse applied to the soil, generally using either direct or very low frequency current (Figure 1).

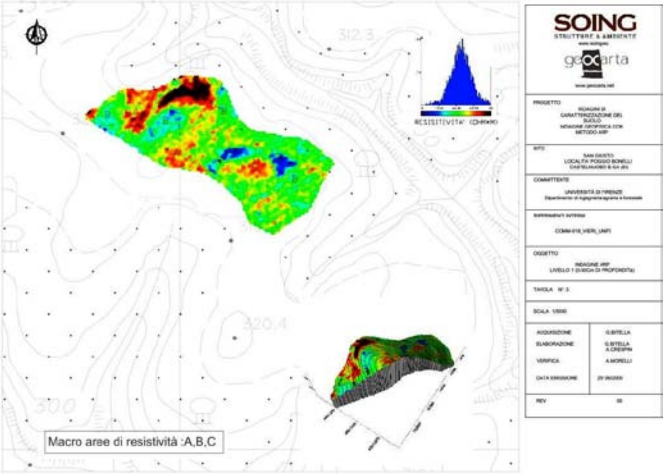

Fig. 1 - Soil resistivity variations in a 3.5 ha vineyard with ARP technique

Electrical resistivity (the unit is Ohm*m), a geophysical parameter, is the inverse of electrical conductivity. The ARP methodology consists in the injection in soil of electric current through one pair of electrodes mounted on teeth wheels and measuring the resulting potential with other three pairs of electrodes, placed at difference distances on the same mobile equipment. Resistivity is related to several soil characteristics and conditions (Costantini *et al.* 2009), such as clay and water content (Figure 2).

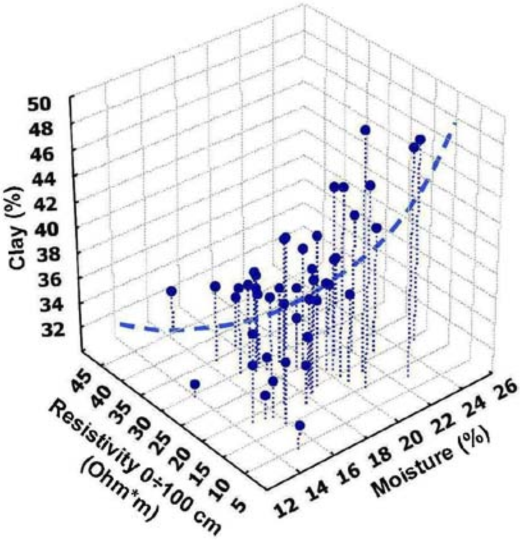

Fig. 2 – Soil resistivity (0-100 cm) related to clay and moisture content

The innovative approach of ARP analysis is represented by a modern integrated two-step approach:

- a no-stop and non-destructive analysis with about 30.000 collected measures per hectare with real time geo-referencing by RTK-DGPS system;

- on the basis of identified homogeneous areas, few and targeted traditional soil surveys are conducted by traditional drilling and profiling, obtaining depth characterization of texture, soil skeleton, macro and micro elements.

The combination of these two techniques and geo-statistical analysis software allow to range over each soil profiling information to all the homogeneous areas on the basis of resistivity parameters (Vieri *et al.* 2010).

The first ARP layer 0-50 cm is the most explored by vine's root system. It tends to concentrate and absorbs along this layer under conditions of good nutrition and water availability.

The second ARP layer displays soil characteristic between 50-100 cm. This volume is affected by deeper roots and is therefore more important when the upper soil layer is less hospitable (nutrients lack) or under stress conditions.

The third ARP layer provides soil information between 100-170 cm. This level, although generally affected by a small percentage of roots (about 3%), is important to determine water and nutrients pool, as well as rocks outcrops or depth harmful stagnation.

The site-specific knowledge of the vineyard soils within the same plot is an important step in the design process of an irrigation system. Due to the dramatic soil variability affecting many vineyards in the typical cultivation areas, technological performance of the irrigation system, defined by the Emission Uniformity coefficient, EU, is not sufficient to grant the efficient use of water. Considering the soil hydrological properties of the in-field homogeneous areas, as well as the different crop vigour, irrigation system should be split into sectors in order to cope with the specific irrigation water needs (i.e., site specific irrigation dose and interval).

THE ARP TECHNOLOGY TO SUPPORT IRRIGATION SYSTEM DESIGN AND MANAGEMENT

A preliminary approach to vineyard irrigation according to the variable rate application approach using the ARP was carried out during the 2009 growing season in the vineyards of Poggio Bonelli farm (Figure 3), belonging to Monte dei Paschi Tenimenti Inc., located in the municipality of Castelnuovo Berardenga, province of Siena. The experience was made in the framework of the three-year research project Qual&Vigna, for the development and testing of precision viticulture techniques and technologies in the Chianti Classico area. The research project was financially supported by Monte dei Paschi di Siena Fundation.

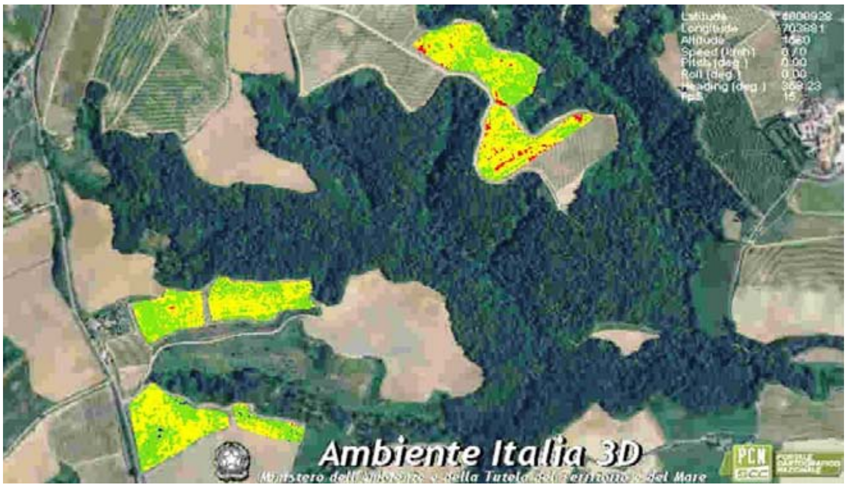

Fig. 3 – Farm vineyards

A simulation was carried out in San Giusto vineyard, a 3.5 ha field cultivated with Sangiovese grape on root stock 420A, according to a plant spacing of 2.50m*0.80m. The survey started with the assessment of the vegetative conditions within the field (Figure 4).

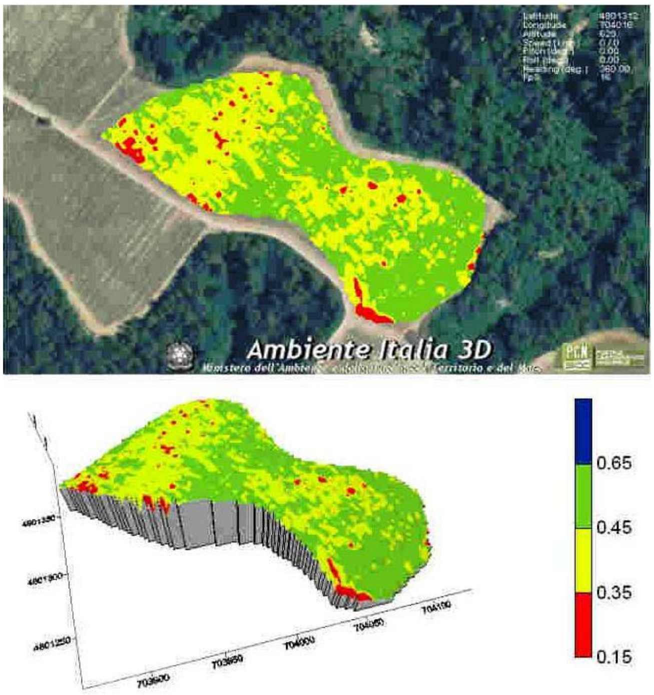

Fig. 4 – In-field variation of vegetation vigour

SOIL CHARACTERIZATION

In-field soil variations were displayed by the different crop vegetation vigour. The vigour map was used as a basis to estimate the different water management needs requested by the different hydrological responses of homogeneous areas bordered within the field. Soil resistivity maps were arranged for the layers 0-50 cm and 50-100 cm respectively, by using the ARP technology (Figure 5), and then overlapped into the 0-100 cm application map.

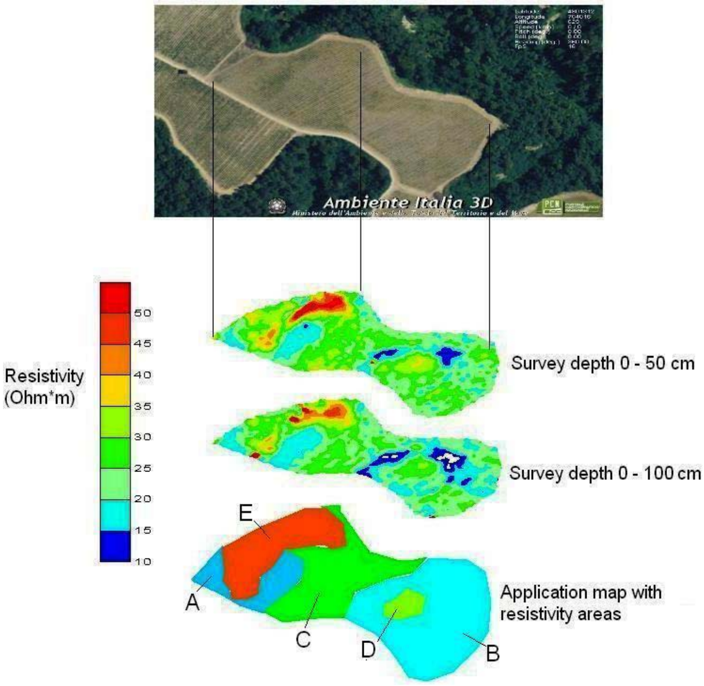

Fig. 5 – Resistivity profiles and application map of the test site

The application map describes 5 areas in terms of homogeneous soil resistivity. Assessing the spatial distribution of these in-field areas allows to reduce the number of soil samples. Reliable sampling density of a 3.5 ha vineyard can be reduced from 51 to 6 soil samples when supported by the geo-electrical survey, without significant accuracy loss (Costantini *et al.* 2009). Moving from such assumption, average soil physical and hydrological characteristics of the five zones (A to E in Figure 5) were defined according to the USDA classification: bulk density (γ_a), field capacity (FC), permanent wilting point (PWP), available water (AW), and the relative irrigation depths (IRR) along the 0-100 cm profile. Values are reported in Table 1.

Table 1. Soil types and properties of the in-field homogeneous areas

AREA		SOIL					IRR
Zone	ha	Type	γ_a (g/cm^3)	FC (mm)	PWP (mm)	AW (mm)	(%)
A	0.3	Clay	1.21	411	199	212	100
B	1.2	Clay-loam	1.23	393	189	204	96
C	1.1	Loam	1.32	324	153	171	80
D	0.1	Sandy loam clay	1.37	283	132	151	71
E	0.8	Sandy loam-	1.47	184	81	103	49

The final basic intake rate varies from 2.5 mm/h (zone A) to 27 mm/h (zone E). Samples show a relevant variation of the soil hydrological characteristics within the field, these variations affecting irrigation management as a consequence.

Optimization of water supply is an important production strategy in high quality precision viticulture. Different soil properties and crop vigour of individual areas result in specific water demand within the field and dedicated management of water supply in terms of irrigation parameters (i.e., irrigation dose, irrigation interval, irrigation time) and system design (i.e., application rate, distribution uniformity).

The multi purpose role of vineyard irrigation is to stabilize crop yield, increase grape quality, save water, avoid groundwater pollution, prevent surface runoff, minimise seasonal water and energy use.

Knowledge of crop vigour, soil physical, hydrological and morphological features of each zone are inputs of paramount importance in irrigation system design and management. In the framework of precision viticulture, a relevant support can be supplied by specific support tools, such as the *Ve.Pro.L.G.s 2008* software (Bertolacci *et al*. 2008).

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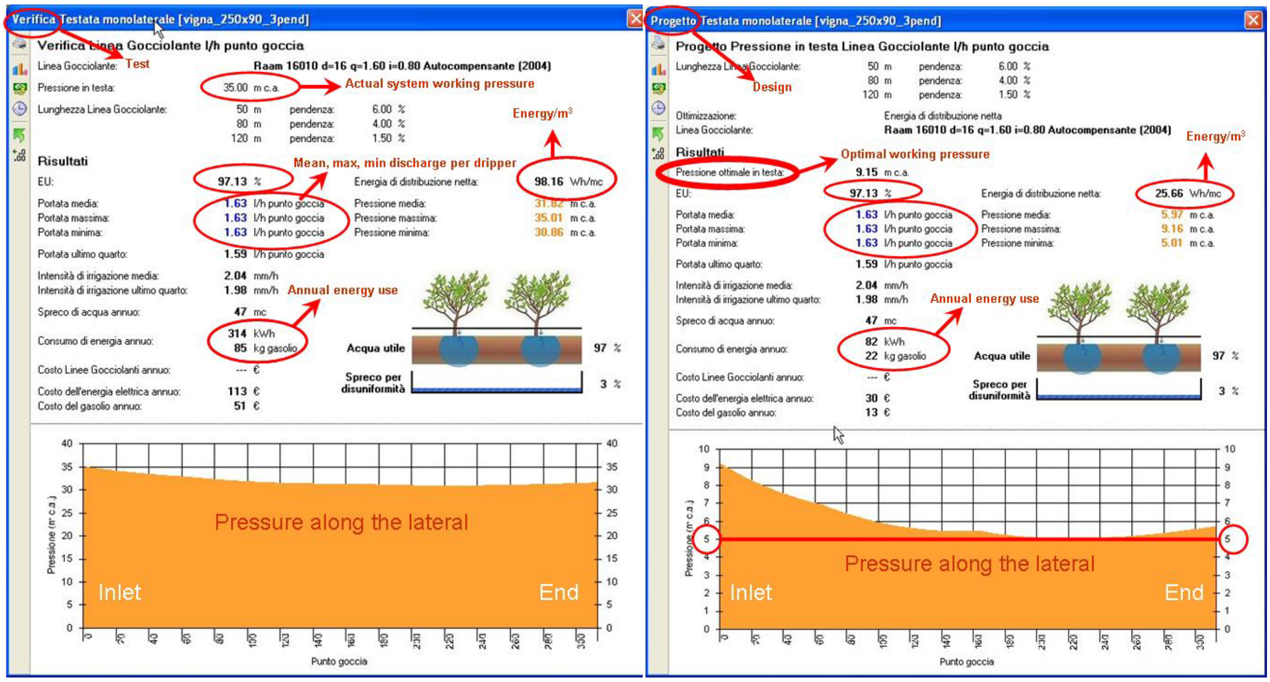
IRRIGATION SYSTEM SELECTION

The contribution of *Ve.Pro.L.G.s 2008* software in both design and test of drip systems can be relevant (Ghinassi and Bertolacci, 2009). It is a user-friendly application software, created by the Laboratorio Nazionale dell'Irrigazione (LNI) of Pisa (Italy), in order to help users in finding suitable technical and economical solutions (equipment choice, system design and test, water and energy use, etc.) in a given farm context (Figure 6).

Fig. 6 - Ve.Pro.LG /s 2008 logo

The software has a database provided with the hydraulic performance of a large number of driplines, tested and characterised by the LNI according to the international standards. *Ve.Pro.L.G.s 2008* has two main objectives:

- support the performance evaluation of existing drip systems, in terms of water and energy use (Figure 7a). Entering the model of the drip line together with some basic field characteristics, namely ground slopes (up to three), row length and working pressure, the software provides information concerning the best performance achievable under optimal conditions (good system maintenance). Minimum, maximum, average discharge per meter of drip line, coefficient of emission uniformity (EU) and distribution efficiency are provided as well.



Verifica Testata monolaterale [vigna_250x90_3pend]

Verifica Linea Gocciolante l/h punto goccia

Linea Gocciolante: **Raam 16010 d=16 q=1.60 i=0.80 Autocompensante (2004)**
Pressione in testa: 35.00 m c.a.
Lunghezza Linea Gocciolante: 50 m pendenza: 6.00 %
80 m pendenza: 4.00 %
120 m pendenza: 1.50 %

Risultati

EU: **97.13** %
Energia di distribuzione netta: **98.16** Wh/mc
Portata media: **1.63** l/h punto goccia
Portata massima: **1.63** l/h punto goccia
Portata minima: **1.63** l/h punto goccia
Pressione media: **31.82** m c.a.
Pressione massima: **35.01** m c.a.
Pressione minima: **30.86** m c.a.
Portata ultimo quarto: **1.59** l/h punto goccia
Intensità di irrigazione media: **2.04** mm/h
Intensità di irrigazione ultimo quarto: **1.98** mm/h
Spreco di acqua annuo: **47** mc
Consumo di energia annuo: **314** kWh
85 kg gasolio
Costo Linee Gocciolanti annuo: --- €
Costo dell'energia elettrica annuo: **113** €
Costo del gasolio annuo: **51** €
Acqua utile **97** %
Spreco per disuniformità **3** %

Test
Actual system working pressure
Energy/m³
Mean, max, min discharge per dripper
Annual energy use

Progetto Testata monolaterale [vigna_250x90_3pend]

Progetto Pressione in testa Linea Gocciolante l/h punto goccia

Lunghezza Linea Gocciolante: 50 m pendenza: 6.00 %
80 m pendenza: 4.00 %
120 m pendenza: 1.50 %
Ottimizzazione: Energia di distribuzione netta
Linea Gocciolante: **Raam 16010 d=16 q=1.60 i=0.80 Autocompensante (2004)**

Risultati

Pressione ottimale in testa: **9.15** m c.a.
EU: **97.13** %
Energia di distribuzione netta: **25.66** Wh/mc
Portata media: **1.63** l/h punto goccia
Portata massima: **1.63** l/h punto goccia
Portata minima: **1.63** l/h punto goccia
Pressione media: **5.97** m c.a.
Pressione massima: **9.16** m c.a.
Pressione minima: **5.01** m c.a.
Portata ultimo quarto: **1.59** l/h punto goccia
Intensità di irrigazione media: **2.04** mm/h
Intensità di irrigazione ultimo quarto: **1.98** mm/h
Spreco di acqua annuo: **47** mc
Consumo di energia annuo: **82** kWh
22 kg gasolio
Costo Linee Gocciolanti annuo: --- €
Costo dell'energia elettrica annuo: **30** €
Costo del gasolio annuo: **13** €
Acqua utile **97** %
Spreco per disuniformità **3** %

Design
Optimal working pressure
Energy/m³
Annual energy use

a **b**

Fig. 7 – Ve.Pro.L.G.s 2008 test (a) and design (b) on vineyard

- support the design of a drip system in actual farm context, to achieve targeted set of performance in terms of water and energy use (Figure 7b).

With the same inputs, the software provides other information (i.e., the pressure to apply at the lateral inlet to maximize EU or, optionally, to minimize energy consumption).

Both for designing and testing, it is possible to:

-screen the drip lines stored up in the data base, according to the crop type (i.e., perennial and annual) and some technical characteristics, such as external pipe diameter, pressure compensating emitters, etc.;

-consider the influence of manifold and lateral slopes;

-describe the line discharge in litres/meter*hour or litres/dripper.

Technical and economical evaluation is allowed by entering data on field dimensions and slopes, crop spacing, laterals and emitters spacing, expected seasonal water supply, manifold type, unit cost of power and fuel, cost and lifetime of a given drip line. Supposing correct maintenance and proper water filtration, the way an existing system should work can be reconstructed. The value of a number of parameters, such as estimated EU (%) and energy required for water distribution (Wh/m^3), is supplied. Outputs can be managed to improve actual performance, according to the specific working conditions and the need for water and energy saving. Taking into account the basic system data and the options set in the input window, values of operating parameters are given. Among them, pressure (m) to be applied at the manifold or lateral inlet to minimize energy consumption or maximize EU, maximal length of the lateral matching the targeted EU, best drip lines in terms of EU (*irrigation efficiency*) or energy use (*energetic efficiency*).

Once such pre-conditions are got, different management strategies (i.e., controlled water stress) can be scheduled.

CONCLUSIONS

Soil survey carried out using the ARP methodology can profitably support precision viticulture by helping vineyard crop and soil zoning. Geo electrical soil investigation can help to reduce the cost of traditional soil sampling, without affecting sampling accuracy. Accurate field zoning is a precondition of precision farming, and the first fundamental step for a conscious application of sustainable viticulture (Vieri, 2004). The need for precise supply of cropping inputs includes also water and other related energetic elements. Assessment of vine water needs must be supported by efficient drip irrigation. Drip distribution and application are often below the potential, and excessive water and energy use are the rule rather than the exception. In-field site specific irrigation system design, management and maintenance is a strategic tool in vineyard irrigation practice. Information yielded by the ARP methodology and the *Ve.Pro.L.G.s 2008* decision support tool, can help overcoming hindrances dividing ordinary from improved precision viticulture.

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