A wireless sensor network for vineyard management in Sicily (Italy)

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Abstract: Wine quality depends on many factors, such as the choice of variety, stock, training system, pruning as well as environmental parameters and cultivation techniques performed in the vineyard. Monitoring the micro-climate of grapevine allows to conveniently perform the most important cultivation techniques (soil management, pesticide treatments, green pruning, harvest) thus reducing the operating costs of the vineyard, and increasing the overall quality of the grapes. The aim of the present study is to monitor the micro-climate of grapevine in order to control spring period hazards, to reduce the operating costs of the vineyard and to increase the quality of grapes. For this purpose a Wireless Sensor Network was used, and a comparison was performed between the data measured by wireless sensors and data provided by a fixed meteorological station of the local government agency (SIAS - Regione Siciliana). The results obtained here showed that, with reference to temperature, the data measured by wireless sensors are considerable different from the data of SIAS measuring station especially for temperatures above 20°C. With reference to relative humidity, there are no differences between the two types of sensors. Our study showed that the microclimate of the vineyard may be considerably different from the climate of the macro-area closest to the plot. Monitoring the micro-climate may thus be crucial as it may represent the key to a rational management of the vineyard, also with regard to a reduction of the costs of certain cultural operations.

Keywords: vineyard, temperature, relative humidity, Wireless Sensor Network (WSN)

Citation: Catania P., M. Vallone, G. Lo Re, M. Ortolani. 2013. A wireless sensor network for vineyard management in Sicily (Italy). Agric Eng Int: CIGR Journal, 15(4): 139−146.

1 Introduction

Sicily has witnessed a considerable increase in high-quality wine production during the past few years. The growing demand of the market caused a great success for Sicilian wines, and quality standards of grapes are consequently growing higher. Wine quality depends on many factors, such as the choice of variety, stock, training system, pruning as well as environmental parameters (with regard to micro- and macro-climate) and cultivation techniques performed in the vineyard. The micro-climate around the grapevine, in particular, is influenced by the whole climatic parameters in the cluster area that governs its growing and ripening.

Monitoring the micro-climate of the grapevine allows to conveniently perform the most important cultivation techniques (soil management, pesticide treatments, green pruning, harvest) thus reducing the operating costs of the vineyard, and increasing the overall quality of the grapes (Catania et al., 2011). In fact, it is well known that certain values of temperature and relative humidity are the main factors causing the most feared diseases of vine (powdery mildew and downy mildew).

In order to achieve seamless and effective monitoring, a thorough sensing of relevant physical quantities must be carried on in the vineyard, during the growth of the grapes and vines. However, this process inevitably results in collecting large amounts of data, whose relevance depends on how effectively higher-lever

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Received date: 2013-07-21 **Accepted date:** 2013-11-21

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information can be extracted from raw measurements. As already mentioned, such information might regard land composition, the presence of parasites or the influence of the application of chemicals, all of which are extremely valuable to the enologist during decision making; more specifically, the present work describes a study on the potential correlation between local and global environmental parameters.

Improving the quality of the overall winemaking process will be achieved by using an innovative infrastructure based on Wireless Sensor Networks (WSNs) (Akyildiz et al., 2002). Furthermore, the same infrastructure may be used to implement a real-time, pervasive, non intrusive, low-cost, and highly flexible distributed data analysis methodology.

Wireless sensors are a class of tiny devices with programmable computing capabilities, equipped with sensing and communication features, and characterized by a limited energy supply. Common wireless sensor networks consist of a large amount of those small nodes; this pervasive technology is typically used for such tasks as environmental and habitat monitoring, motion monitoring or, more generally, tasks that require collecting data and extracting information from remote or hostile environments. Sensed data flows from remote nodes toward a sensor designated as the sink, the base station, that acts as a collector and an interface to the external world.

Wireless sensors are comparable to fully functional computers, hence, they are not just able to collect measurements of physical quantities mirroring the sensed phenomena, but also to perform distributed computations as those quantities traverse the network toward the sink node. Data are thus shared amongst the sensors, they may be manipulated or merged in order to reduce the overall transmissions and enhance the network lifetime.

The most relevant difference between traditional networks and wireless sensor networks is represented by their limited power supply. Typical usage of those sensors requires them to operate in inhospitable sites, so there is little room for human intervention after deployment; an obvious goal is thus the maximization of network lifetime or, in other words, the minimization of any possible waste of energy.

Recently, WSNs have also been employed in the specific area of farming monitoring and a few preliminary works describe applications for precision agriculture (Baggio, 2005; Chiti et al., 2005; Zhang, 2004). Some studies have been performed regarding a prototypal smart sensor array for measuring soil moisture and soil temperature; for instance scheduling irrigation in cotton is targeted in Velledis et al. (2008), while greenhouse climate control using wireless sensors is analyzed in Carrara et al. (2008); however, applications of wireless sensors in agriculture and food industry are still not widespread. As regards to applications involving vineyards, some researchers have studied the peculiar needs and priorities of people working in such environments in order to investigate the potential for sensor networks in agriculture using ethnographic research methods (Burrel et al., 2004). Others (Galmes, 2006) have considered the expected lifetime of a wireless sensor network deployed on a fictitious vineyard from the energy consumption point of view. Finally, an interesting application of wireless sensors in a vineyard was performed by measuring some characteristic parameters of the plants, such as leaf temperature, growth rate, diametric growth of the trunk, photosynthesis and transpiration (Masi et al., 2007).

An immediate advantage arising from the adoption of a WSN-based approach in agriculture is that corrective actions on the cultivations may be timely and selectively chosen; furthermore, the system allows to build a history of past events, and stored data may be analyzed in order to extract potentially hidden correlations among the sensed environmental variables and the obtained results. The availability of a considerable amount of precise data, superior to what is commonly attainable through traditional random sampling, allows for the construction of accurate models, and thus favors the proposals for cultivation process improvements.

This methodology does not merely suggest to increase the granularity of sensing by deploying a large number of sensors in the environment, or to increase the sensing rate; rather, the proposed infrastructure offers the possibility of carrying on advanced analyses by acting as a more complex, intelligent, distributed system. The technical advantages arising from the pervasive control over the vineyard conditions will then allow for a rationalization of the interventions and result in an increase in the overall quality of produced wine (Aiello et al., 2012; Carrara et al., 2005; Catania et al., 2013).

The aim of the present study is to monitor the micro-climate of the grapevine and thus to control the pathological and entomological diseases typical of the spring period, to reduce the operating costs of the vineyard and to increase the quality of grapes. For this purpose a Wireless Sensor Network was used, and a comparison was performed between the data measured by the wireless sensors and the data provided by the fixed meteorological station of the local government agency (SIAS - Regione Siciliana). Therefore, a cost effectiveness analysis was carried out for assessing the sustainability of this innovative system.

2 Materials and method

2.1 Test site

The research was developed in 2012 within a project which included the installation of a wireless sensors network for continuous monitoring the most relevant environmental parameters in the vineyard at Aziende Agricole Planeta (Menfi, Sicily).

The 8-year vineyard, in the phase of increasing productivity, was trained with a hedgerow system; the planting layout was 2.50 × 1.00 m, and the variety was Chardonnay. The experimental plot, set at 220 m above sea level on average, was flat and about 1 ha wide. Thirty sensor nodes were uniformly distributed over the entire area, and each node was located at the 2nd line of the hedgerow steel wires (1.00 m off the ground).

2.2 Wireless sensor network

Commercially available boards were used in order to speed up the design process; however, they had to be customized due to the presence of application-specific sensors.

The requirements elicitation phase, conducted at the earlier stage of the project, had pointed out that the two most relevant factors for the development of healthy grapes are temperature and relative humidity. Nodes were thus equipped with the corresponding sensors; in particular, the Sensirion SHT11 combined temperature/relative humidity sensors were used (Table 1).

Table 1 Sensors used in the experimental tests and their characteristics

Measure	Sensor	Characteristics
Temperature and relative humidity	Sensirion SHT11	Temperature range: -40°C to +123.8°C Temp. accuracy: +/- 0.5°C @ 25°C Humidity range: 0 to 100% RH Absolute RH accuracy: +/- 3.5% RH Low power consumption (typically 30 µW)

A final consideration regards the connection between the sensory network and the data storage server. This was realized through a IEEE 802.11 (WiFi) channel in order to allow future extension of the same monitoring structure to nearby fields. The bridge between the IEEE 802.15.4 network used by the sensor nodes and the WiFi one is realized by a Stargate board, equipped with both interfaces.

Different types of nodes were deployed in the main monitored area; the characteristics of their processors boards and radios are summarized in Table 2.

Table 2 Characteristics of the different types of sensor boards employed in the tests

Sensor Type	CPU			Memory	Radio		
	Description	Energy per computation	Sleep power		Description	Energy per bit	Idle power
TelosB	TIMSP430 16 bit	Active power 3 mW	15 µW	48KB RAM 1MB Flash	CC2420 250Kbps IEEE 802.15.4 / Zigbee	430 nJ b^{-1}	7 mA
Stargate	Intel PXA255 32 bit	1.1 nJ/instr 1 mJ/beamform	20 mW	64MB SDRAM 32MB Flash	Orinoco Gold 11Mbps IEEE 802.11b	90 nJ b^{-1}	160 mA

Figure 1 shows a scheme of the actual deployment in the vineyard; all nodes were TelosB motes equipped with temperature and relative humidity sensors. As shown in the picture, they were deployed every other row, and at a distance of 2 m from each other along the hedgerow, in order to provide coverage of the whole field along its diagonal. The rightmost side of the picture shows a detail of the deployment, highlighting the distances between the nodes.

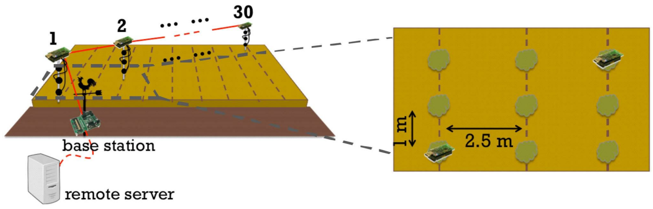

Figure 1 Scheme of the nodes position in the vineyard

As regards to the processor and radio units, the TelosB nodes were selected as they offer good performances in terms of transmission range; moreover they are already equipped with an integrated sensor board containing the sensors necessary to sense micro-climate-related quantities. Such nodes are commercially available and the ones used for this project are produced by Crossbow; they are fairly configurable, for instance new sensors may be added, and, above all, their behavior may be fully programmed via an ad-hoc programming language.

In our application, the nodes' behavior was customized to meet the specific application's needs. The sensing rate of each node was not required to be particularly high, and was set to 1 time per hour; this choice appears to be reasonable also for the goal of maximizing the network lifetime.

Nodes in the vineyard network communicate on a IEEE 802.15.4 link, but at the application layer, a specialized protocol was designed in order to ensure robust data gathering, while limiting energy consumption.

In order to optimize the overall network lifetime, we exploited some of our previous research experiences in the field of data gathering for WSNs, and implemented a customized version of our protocol for robust and energy-efficient data gathering on the nodes of both networks. As already explained, although the deployment of the nodes is statically set, both environments present dynamic characteristics, so that transmissions may still incur in losses.

Our previous work proposed a network-layer protocol for WSNs based on the IEEE 802.15.4 standard (Messina et al., 2007); the protocol was devised to provide reliable data gathering in latency-constrained applications, and exploited both the flexibility of the IEEE 802.15.4 MAC layer and features of data aggregation techniques, such as implicit acknowledgment of reception. The proposed protocol operates over the existing MAC layer and provides reliable communication, while managing power saving and synchronization among nodes. Without relying on MAC-layer acknowledgments, it implemented caching and network-layer retransmissions, triggered upon detection of a link failure.

2.3 Environmental parameters monitoring

The monitoring of the main environmental parameters was performed in 2012 from April 17th to May 27th. Collected data were divided into four ten-days periods respectively named "A" (April 17th-26th), "B" (April 27th-May 7th), "C" (May 8th-17th) and "D" (May 18th-27th). This is the most critical phase for the control of the main hazards for grapevines (such as mildew, powdery mildew and grape moth) because of the special environmental conditions that may occur. In addition to the measurements of the main environmental parameters performed by the wireless sensor network, the data collected from the Sicilian Agricultural Information Service (SIAS) station located in Sciacca were examined; this was the nearest available station to the site under investigation. SIAS is a service of the Sicilian Region, Department of Agriculture and Forestry that, through the combined use of meteorological, climatic and agronomic knowledge provides a very useful support for farm management, forestry and animal husbandry. Its network is composed of telemetry stations with varying number and type of configured sensors (therefore, different meteorological quantities are detected at each station). In this study, air temperature and relative humidity, averaged over a one hour time span, were considered for the period under investigation. The aim was to compare the data collected by SIAS, covering a very wide area, considering that the distance between the station and the studied vineyard was about 10 km, with the precision data reported by the platform of wireless sensors installed for our purpose.

Therefore, this research was aimed at identifying possible critical locations of focus of cryptogams and/or insects that may be harmful precursors of disease and infestation to the grapevine, and whose symptoms only appear after a certain period of time, due to the long incubation phase of the parasite. In order not to compromise the quality of the product, the chose remedy implies intervening with curative treatments of systemic nature, or following the traditional technique of the treatment schedule; unfortunately, both techniques present negative effects due to potential environmental damages, and to the cost of managing the vineyard.

The vegetative growth of the plants was also evaluated by monitoring the length of 70 randomly selected shoots, each on a different plant of the entire plot, as this constitutes an important parameter for identifying the location of parasites.

We also took into account the costs required to implement the system described in this work and its maintenance costs.

2.4 Statistical analyses

Temperature and relative humidity values collected by WSN and SIAS for the thirty nodes were subjected to ANOVA and Tukey's test at the 95% confidence level (Statgraphics Centurion, Statpoint Inc., USA, 2005).

3 Results and discussion

The average growth of the shoots in the period under observation is reported in Figure 2. It shows that the rapid growth of the shoots stops at the end of the third period reaching an average length of 1.10 m. It follows that the most critical period relatively to attacks by pathogens and insects goes from the beginning of the shoots development to the end of the third ten-days period (periods A, B and C). The plot shows that the increase is marked in the period "A" with an increase of about 55%, followed by "B" which shows an average increase of 30%, and finally "C" where an average increase of 17% occurs. In the period "D", however, the growth shows a significant slowdown (only +4%) as the plants approach the end of the flowering stage, and fruit setting begins.

No statistical significant differences were found between temperature and relative humidity data recorded by the thirty sensors of the wireless network; therefore, the average values recorded by all sensors were taken into account.

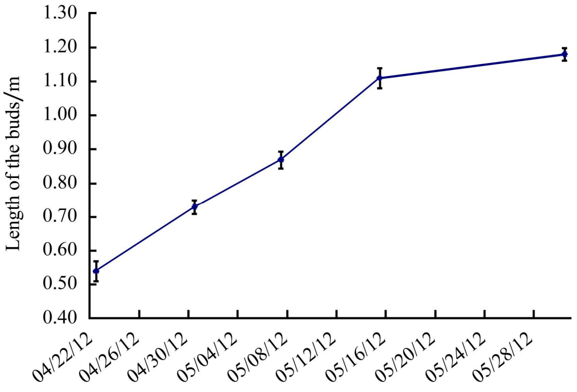

Figure 2 Mean growth of the shoots during the examined period

Figure 3 and Figure 4 respectively report the average hourly values for temperature and relative humidity, both for the wireless sensors and the SIAS station.

For the period "A", in which vegetation had a very small growth, but was very sensitive to the major adversities, the wireless platform reports temperature values ranging from 7°C to 36°C, while SIAS shows values between 10°C and 27°C. In particular, a larger difference may be noticed in temperature values detected by the two systems during daylight hours; there are, in fact, differences of up to 7-8°C, particularly when temperature was higher than 20°C. In the same ten days the values for relative humidity recorded by the two systems are very similar to each other. Overall, the relative humidity values in the first ten days are between 27% and 96%.

With reference to the period "B", when vegetation was developing, wireless sensors gave temperature between 6°C and 38°C, while SIAS recorded values between 8°C and 28°C. Also in that ten days, a considerable difference in the temperature values recorded by the two systems during daylight hours were reported; there were, in fact, differences between the two measures of up to 15°C, when temperature was higher than 20°C. In the same ten days, relative humidity values measured by the two systems are very similar and vary between 19% and 95%.

In the period "C", when the development of vegetation continued, wireless sensors detected temperature values between 9°C and 33°C, while values recorded by SIAS were between 11°C and 30°C. Again, there was a noticeable difference in the temperature values recorded by the two systems during daylight hours;

the maximum difference between the two measures was 10°C. During the same ten days, relative humidity recorded by the two systems are similar, with values between 15% and 99%.

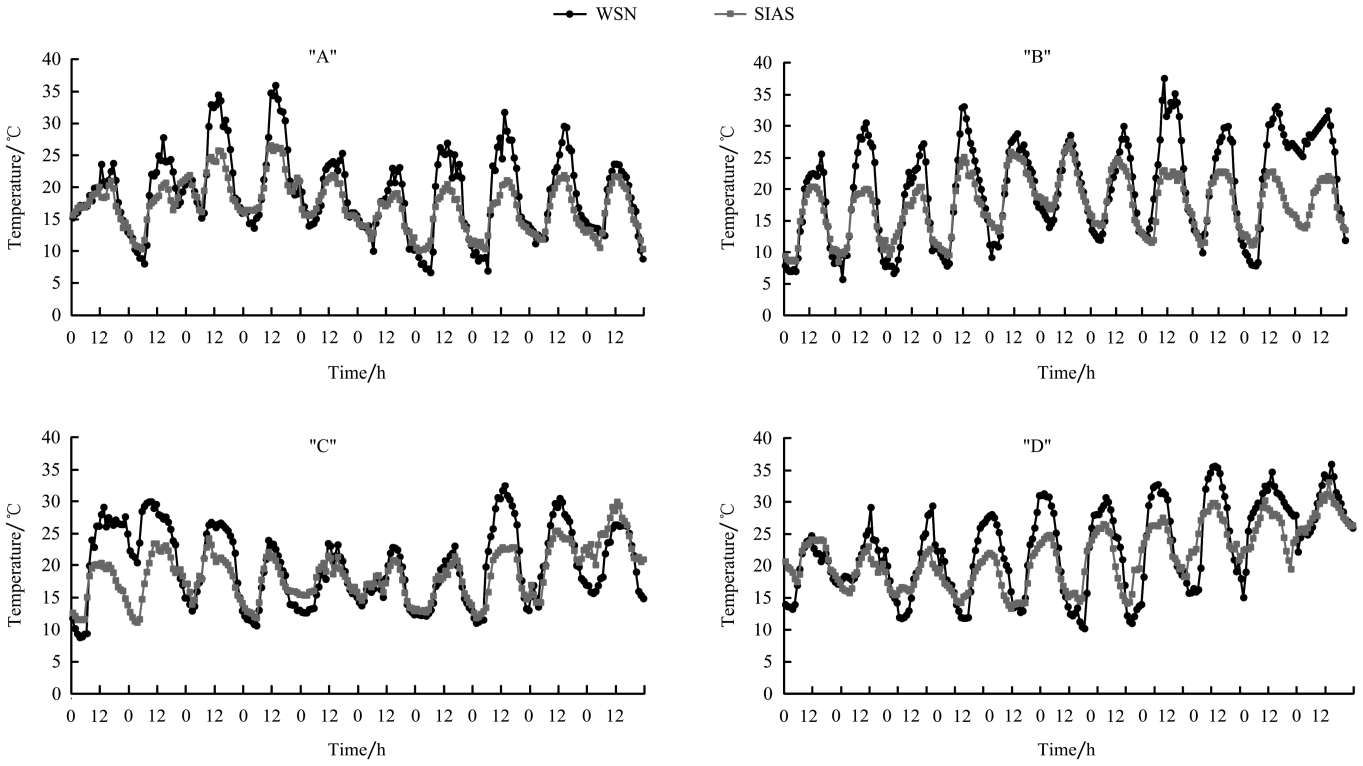

Figure 3 Temperature measured by the sensors during the monitored period (four ten-day periods). Comparison between WSN and SIAS data

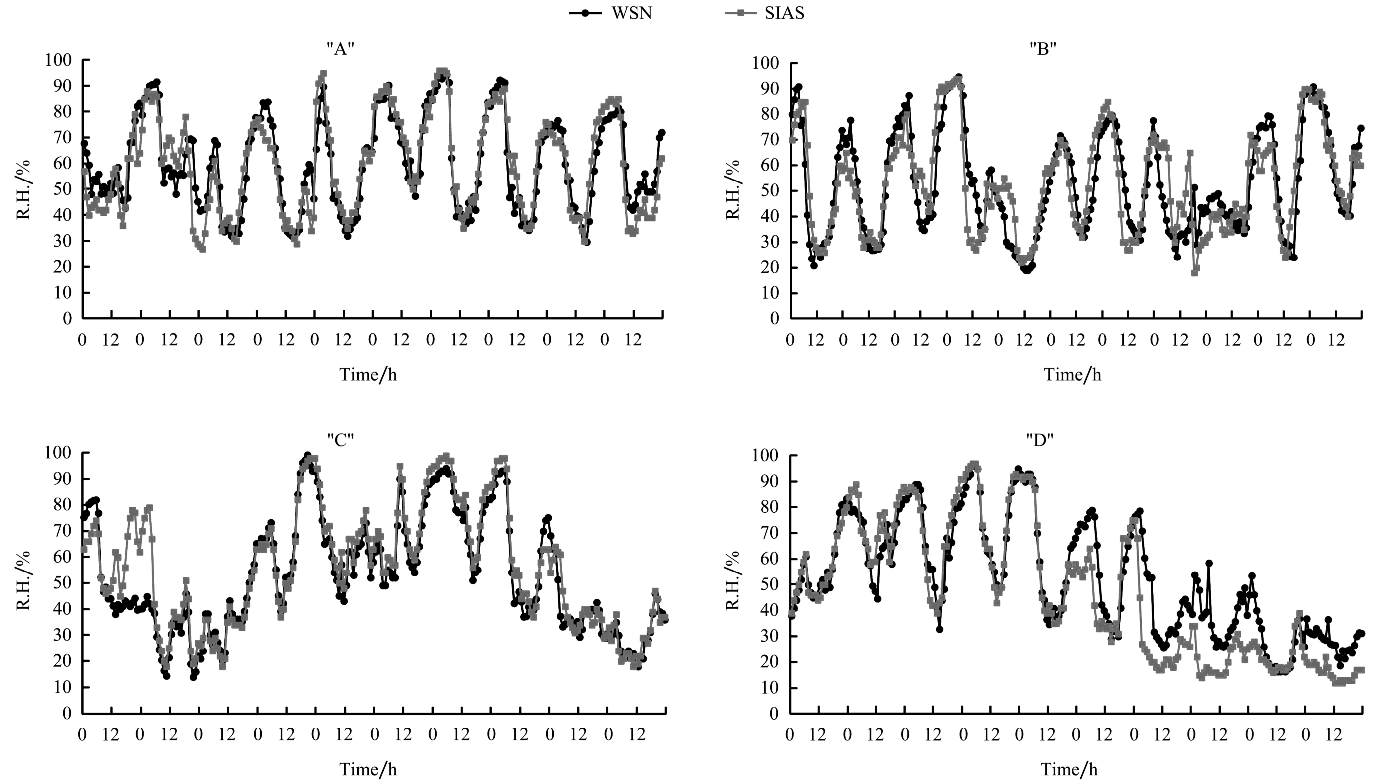

Figure 4 Relative Humidity (R.H.) measured by the sensors during the monitored period (four ten-day periods). Comparison between WSN and SIAS data

With reference to the period “D”, where vegetation development significantly slowed down, the wireless platform provided temperature values between 10°C and 36°C, while SIAS recorded temperature values between 13°C and 33°C. During daylight hours there were the highest differences in the temperature values recorded by the two systems of up to 6°C. The values for relative humidity recorded by the two systems in ten days “D” are very similar, and vary between 14% and 97%.

Correlating climate and vegetative development data, we can say that the WSN system is much more useful than SIAS because the actual temperature values measured in the bunches allow to obtain a higher safety in plant management than the SIAS system with reference to possible parasitic attacks.

As mentioned earlier, the relevant phenomena to be monitored were temperature and relative humidity. In order to obtain a satisfying trade-off between precision and cost of the entire deployment, we chose to install sensor nodes only on some poles in the hedgerows, as shown in Figure 1. The most relevant piece of equipment with respect to cost is the TelosB node, which must be replicated for each monitoring point, proportionally to the field size. TelosB is now commonly available off-the-shelf, at limited cost, and the same holds for the Sensirion sensors; however, in the view of extensive deployment additional saving may be obtained by coupling several sensors to a single sensor node in each pole. With this caveat, the overall cost for a single pole can be contained to no more than about 100€. A fixed cost is further represented by the required node and corresponding sensors for the base station, deployed at the field limit and necessary to provide connection to the remote server. The cost of this additional equipment is comparable to the previous one (depending on the choice of sensors, it will amount to no more than 300€) but again, it does not need to be replicated so it will not heavily affect the overall cost. A reliable estimate for the whole prototype is thus 30 × 100 + 300 = 3.300 €. A final note regards maintenance costs which, unlike other monitoring equipment, are extremely low since such nodes, when carefully programmed, may remain active without direct supervision even for a period of a few months, up to a year.

4 Conclusions

The aim of this work was to monitor the main environmental parameters of vineyard, in order to control the more common hazards of the grapevine for the period under consideration (April - May).

The following considerations can be drawn from the presented research:

- with reference to temperature, the data measured by the wireless sensors showed considerable differences compared to the data of the SIAS measuring station especially for temperatures above 20°C, the maximum difference between the two measures was equal to 37%;
- with reference to relative humidity, there are no differences between the two types of sensors.

These differences in the temperature values are certainly to be attributed to the different methods of collecting environmental data for the two systems: SIAS includes a portion of territory several tens of hectares wide through traditional hut weather. WSN, on the contrary, allows for timely detection of the basic environmental parameters for the sustainable management of agriculture.

In conclusion, by continuously monitoring the environmental parameters within the vineyard, it is possible to obtain useful information concerning the potential arise of serious hazards for grapevines. Moreover, the proposed system is not very expensive compared to the benefits it can provide. Our study showed that the microclimate of the vineyard may be considerably different from the climate of the macro-area closest to the plot. Monitoring the micro-climate may thus be crucial as it may represent the key to a rational management of the vineyard, also with regard to a reduction of the costs of certain cultural operations.

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