



## XVII<sup>th</sup> World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)  
Québec City, Canada June 13-17, 2010



### WIRELESS SENSOR NETWORKS FOR ENVIRONMENTAL MONITORING IN PRECISION VITICULTURE

ANTONIO BRASA RAMOS<sup>1</sup>, FRANCISCO MONTERO RIQUELME<sup>1</sup>, FRANCISCO MONTERO GARCIA<sup>1</sup>, LUIS OROZCO<sup>2</sup>, JUAN JOSE RONCERO<sup>2</sup>

<sup>1</sup>ETS de Ingenieros Agronomos, University of Castilla-La Mancha, 02006-Albacete, Spain, Antonio.brasa@uclm.es

<sup>2</sup>IA, University of Castilla-La Mancha, 02006-Albacete, Spain

#### CSBE100698 – Presented at Section I: Land and Water Engineering Conference

**ABSTRACT** A Wireless Sensor Network (WSN) can be successfully used for environmental monitoring. WSNs represent nowadays one of the most exciting technologies. Data acquisition of environmental parameters by means of processing of satellite images to be used in Geographic Information Systems (GIS) and image analysis software is a time consuming process. The use of WSN currently promises to shorten time to acceptable margins. This paper shows the results of a research project developed in a vineyard of Castilla-La Mancha, Spain, where an experimental network was set up, consisting of 12 nodes with up to four different sensors measuring ambient temperature and humidity, soil moisture (water content and potential), soil temperature, photosynthetically active radiation. Data transmission follows the wireless ZigBee standard, due to its low power needs and simple networking configuration. The nodes can communicate with a gateway unit, which can transmit the information to other computers via LAN, WLAN or Internet. The results achieved in this project could help farmers use this new technology in modern grapevine growing. One key milestone was the development of a computer-based information system: a high-valued decision tool for the grapevine grower. The ultimate aim is to develop a full operational prototype for data acquisition and processing enabling the easy analysis of the data by the farmer. A better choice of grapes, leading to better wines, is the first step that wine-producers should consider, but an important constraint is the ease with which the systems can be deployed in an open field.

**Keywords:** Wireless sensor network, Precision viticulture, Geographic Information Systems.

**INTRODUCTION** Precision Viticulture (PV) recognizes that wine grape yield within vineyards can be variable (PVA, 2007). Thus, vineyard management is targeted to areas which have similar growing characteristics, quantify how these areas within a vineyard perform, use the information to understand the reasons for the differences, and make better management decisions to increase production efficiency, profitability and sustainability (Bramley et al., 2006). In addition, its perennial nature suggests that yield spatial variation will maintain some behavioural pattern from one year to the next (Arno et al., 2009).

The implementation of PV demands intensive data manipulation. Data for some variables can be obtained by means of remote sensing techniques; for others, however, direct field measurements with sensors are essential, either with stationary equipment (weather stations) or portable devices operated manually (Camilli et al., 2007). Sensors allow to manage a small area specifically (Cook and Bramley, 1998). Akyildiz et al. (2002) describes that sensor networks are used for a variety of applications, including agricultural monitoring.

WSNs are networks of small sensor nodes with limited processing capacity that communicate over short distances, normally using radio frequencies. The sensor nodes are deployed inside the field to be monitored (Camilli et al., 2007); they are fitted with an on-board processor to locally carry out simple computations and transmit only the required and partially processed data (Akyildiz et al., 2002).

At the present time, however, very few practical examples of the use of WSN in agriculture are available in the literature (Cerpa et al., 2001; Burrell et al., 2003; Wang et al., 2006). However, Akkaya et al. (2006) envision that WSNs will be part of the future Internet where real-time information will be queried through physical sensors deployed almost everywhere.

The objectives of this paper are twofold: Firstly, to set up an experimental platform to design and implement various mechanisms aiming to enhance the performance of this type of networks, such as reconfiguration, security algorithms and power consumption. Secondly, to point out PV concepts related to the spatial variability of plant performance by measuring key environmental parameters such as ambient temperature and humidity, soil temperature, water content and solar radiation.

## **MATERIALS AND METHODS**

**Experimental design** A two-phase experimental methodology was used. The first phase validates management solutions during acquisition, processing, transmission and reception, and tests the operational issues under critical environmental conditions. The second experimental phase was performed under real operating conditions in a vineyard in order to analyse the spatial variability of relevant environmental parameters affecting wine quality production. The aim was to collect data on environmental parameters involved in relevant plant physiology processes: temperature, humidity and radiation. At each sampling site, sensor devices were deployed within the canopy of a grapevine plant selected to be representative of its surrounding.

The vineyard (*Vitis vinifera* L.) of 1 ha is located close to Albacete city, Spain, at 690 m a.s.l. There are 2240 drip-irrigated grape trellised plants. Sensors were deployed at 12 nodes in a 25x40-m grid. Camilli et al. (2007) considered grid distances less than 30 m is a setup compatible with the PA requirements. The experiment started in spring 2009.

**The Wireless Sensor Network** The network consisted on 12 devices belonging to the ēKo® series (Crossbow Technology, Inc., San José, CA, EEUU). The eN2100 ēKo node is a fully integrated, rugged outdoor sensor package that uses energy-efficient radio and sensors for extended battery life and performance.

The ēKo node integrates an IRIS family processor/radio board and antenna that are powered by rechargeable batteries and solar cell. In addition, provides a direct sequence spread spectrum radio (DSSS) supporting the 2.4 GHz global ISM band. ēKo node is capable of outdoor radio range of 500 to 1500 feet depending on deployment. The nodes come pre-programmed and configured with Crossbow's XMesh low power networking protocol. This provides plug-and-play network scalability for wireless sensor network.

The nodes extend their radio range by hopping messages. All ēKo nodes can originate sensor data and also forward data from other ēKo nodes (see fig. 1). ēKo nodes without sensors can be placed anywhere to act as repeaters if required. Each node monitors the radio traffic in its neighbourhood and keeps track of possible alternate radio paths. If one path is blocked or degrades, it will switch to an alternate path.

The ēKo gateway stores and forwards (optional) data from the sensor network. The ēKoView web service allows users to remotely view sensor data via the internet and monitor the network. The gateway will connect to any standard Ethernet hub or router.

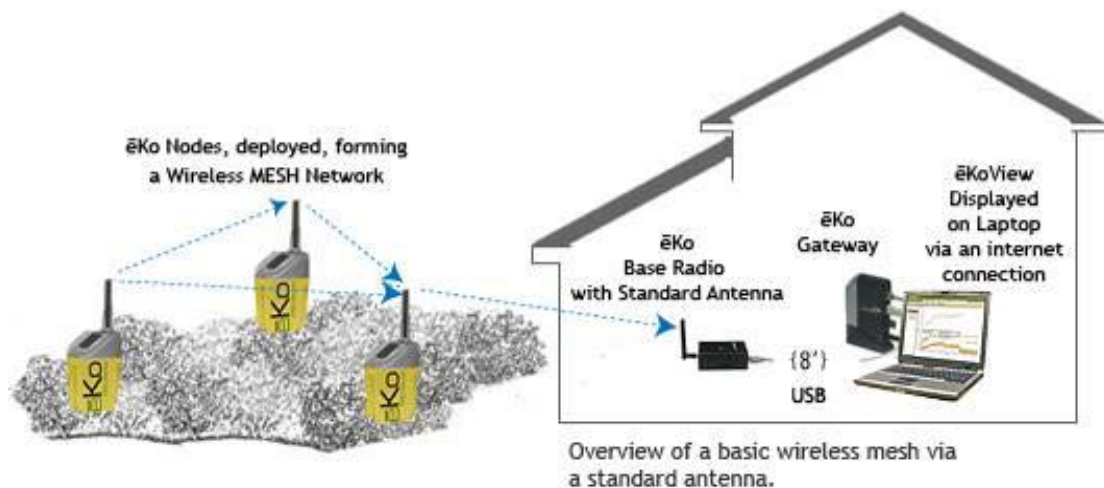


Figure 1. Operating layout of the ēKo network([www.xbow.com](http://www.xbow.com))

The ēKo Pro Series system can support a wide range of external sensors from different manufacturers. Its plug-and-play Environmental Sensor Bus (ESB) architecture provides the versatility to interface both smart and custom sensors with direct plug-in.

Each node can support up to four sensors, one for each port. The system can be easily enhanced with various sensors such as soil moisture, ambient temperature and humidity, soil water content, solar radiation, etc.

- **Ambient temperature and humidity (eS1201):** This device works using the “Sensirion-SHT75” sensor which provides the following characteristics: 0 to 100%RHI humidity range, -40°C to 70°C of temperature range. Its certified accuracy is +/-3% (10 to 90%RHI) and +/-2°C.
- **Soil moisture and soil temperature (Watermark) (eS1101):** This is a Davis device adapted to the Switchcraft EN3 connector. Its water potential range widens

- from 0 to 200 cbar with +/-5% accuracy. It also includes a soil temperature sensor (Sensirion-SHT75) for possible water potential measure corrections.
- **Solar radiation (eS1401):** The eS1401 uses the Davis Solar Radiation sensor and measures global radiation, both the direct and diffuse components of solar irradiance. It measures a range from 0 to 1800 W/m<sup>2</sup> with +/-5% accuracy.
  - **Soil water content (eS1110):** The eS1110 uses the Decagon EC-5 which obtains volumetric water content by measuring the dielectric constant of the media. Its range widens from 0 to 100% of volumetric water content with a maximum +/-3% accuracy depending on the soil type and water salinity.

The sensors conformed to the Guide to Meteorological Instruments and Methods of Observation (World Meteorological Organization, 2008). Data are transmitted every 15 minutes from the nodes to the gateway unit.

**Data Analysis.** The data analysis was carried out in two main steps. The first one was a statistical analysis of the raw data using SPSS Statistics 17.0. A multiple comparison test was done in order to find data patterns and anomalies. These anomalies provided us with feedback information to enhance the WSN prototype and the experimental design.

Once daily data patterns were revised, the second step was a geostatistical analysis (Kravsehnko and Bullock, 1999) looking for spatial variability trends. This process can be broken down into the following steps:

- Explore the data (Histograms, Voronoi maps, Semivariograms, etc.)
- Fit a model (IDW, Kriging, Cokriging, Radial Basis, Global Polynomial, etc.)
- Perform diagnostics and compare the models

This methodology was implemented by using the ArcGis software (ESRI, 2009).

## RESULTS

**WSN Prototype** The system architecture, both hardware and software, was successfully tested in the lab under controlled conditions with a limited number of three nodes. Temperature and humidity sensors (SHT75 Sensirion, CA, USA) were calibrated by using a plant growth chamber CMP 4030 (Conviron, Winnipeg, Canada).

After passing the test, the sensors were deployed in the field. Occasionally, some anomalies were found in the recorded data due to different situations such as network saturation, missing data packages during the deliver-receiving process or power cuts. These situations caused data errors and gaps in the data set continuity. The battery management systems are critical, especially in the data's deliver-receiving process, provoking unsuccessful connections in those devices with partially charged batteries that might turn down the whole network activity. Another important problem has been the instability in power supply in terms of voltage peaks or electric supply cuts. These issues have caused serious damage in the gateway's boot-up system and the corruptions of its files therefore, long data series during the vegetative cycle of the vineyard were lost. We have concluded that the system nodes are able to sustain themselves based on solar energy alone (Morais et al., 2008) as well as the gateway device trying to reach the overall energy system autonomy.

The longest continuous data time period was chosen for the statistical analysis of the raw data. The 66705 collected data packets, corresponding to the 33 days around vineyard bloom, were depurated. The statistical analysis let us identify malfunctioning nodes that seemed to be working properly. Two main problems concerning data quality were found. In one hand, some nodes revealed continuity problems in operation, delivering one same data packet repeatedly; this problem alters the means calculation. On the other hand, out-of-range measurements were registered by some sensors under specific local conditions, particularly with high temperatures under direct solar radiation. The most representative parameter that is not affected by these troubles and could be used in the geostatistical analysis was the daily minimum temperature.

The multiple comparison test showed the homogeneity of the average daily data. However, when the full data sets were analyzed, remarkable differences were found in certain parameters. These differences let us have an insight view of the intrinsical plot's variability. The outcomes of this preliminary test lead us to make changes in the sensor canopy location or replace the out of range ones, improving the experimental WSN prototype design.

**Agricultural Information System** The large amount of data to be collected with a very high spatial sampling density and in order to improve our ability to understand yield variability, a software tool for visualization and analysis of monitoring data as well as the management of the network was developed. *WiseObserver* is an intuitive and powerful interface allowing all kind of users to approach network data treatment and visualization.

*WiseObserver* has been developed in C# .net and uses a database with data coming from the WSN. One important requirement is that the system must be independent of the hardware platform and software of the WSN, as well as independent of the scope of application altogether. In order to obtain these technological independence and use flexibility it is necessary the division of the application in modules to make easy certain functionalities and satisfy certain requirements.

The application includes several modules with different functionality to fulfill all its requirements:

- **Evolution Chart:** It includes different graphic formats to represent data evolution in a certain monitoring period. The tool facilitates graphic generation in different formats: block, evolution, bars, etc., and also statistical functions. Another important characteristic of this module is that it allows the comparison between graphs.
- **Interpolation Maps:** It is a special visualization module which generates contour maps, and offers very fast instantaneous data visualization. Interpolation maps are designed to work with all kinds of outdoor monitoring applications, but future versions of the tool will include calculations for different interpolation maps. With this additional functionality, *WiseObserver* will also extend its scope of use to almost all monitoring wireless sensor network applications
- **Evolution Video Generation:** This module generates videos mounted with sequential contour maps to cover a certain period of time.
- **External Data:** This module makes more flexible the scope of application of the tool, incorporating related external data not provided by the network and

manually added. The tool uses these data to perform evolution charts and contour maps and can be compared with data coming from the WSN.

- **Report Generation:** This module has been designed to generate automatic reports based on WSN data and allows the inclusion of graphs and maps generated by means of evolution charts and interpolation maps modules.

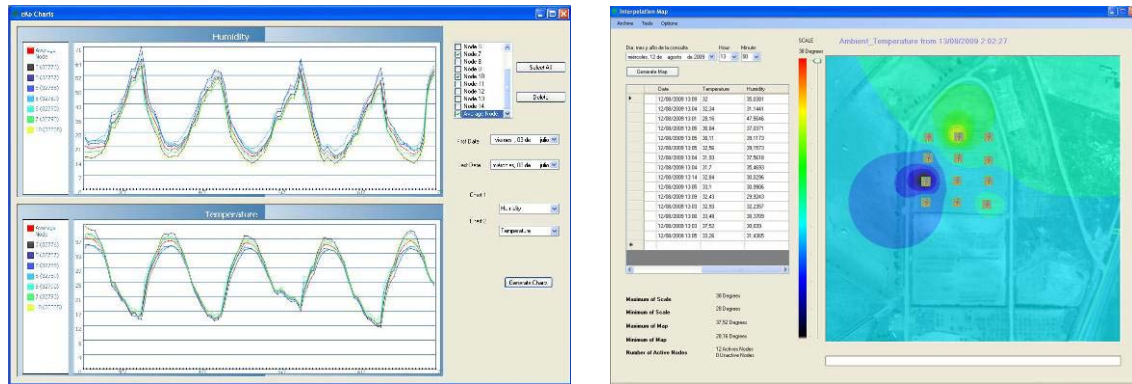


Figure 2. WiseObserver Graphical User Interface for Evolution Chart (left) and Interpolation Maps (right)

**Spatial variability.** Since the land characteristics are continuously varying, the estimated yield over the interpolation is more operational than discrete measurements on certain points (Lamb and Bramley, 2001).

As a result of the data analysis methodology described in this paper, the 23rd of May was selected as the most suitable day for the geostatistical analysis. The Duncan multiple comparison test showed two different homogenous groups with a 0.10 alpha value for this day. Therefore, the final data set chosen to perform the geostatistical analysis, was the 23rd of May minimum temperature of each node. Exploring the data set, we got the outcomes shown in Figure 3.

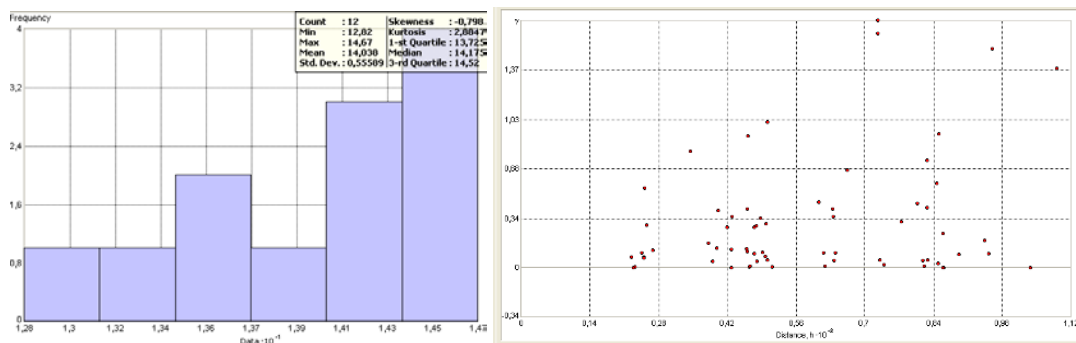


Figure 3. Data distribution of minimum temperature for the case study (May 23, 2009): Histogram (left) and Semivariogram (right)

Fitting a model means choosing a surface interpolation method to estimate data values at locations where measurements have not been taken. To fit our model, firstly, an Interpolated Distance Weighted (IDW) method with standard settings was applied to the data set. Then, kriging methods with different settings were also applied. Figure 4 shows the results of these interpolation methods.

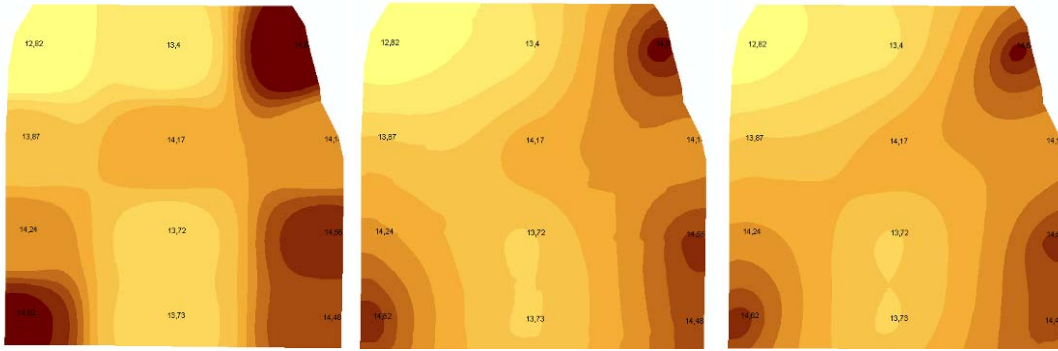


Figure 4. Spatial distribution results of several interpolation models applied to the case study (May 23, 2009): IDW optimum (left), Ordinary Kriging default (center) and Ordinary Kriging exponential (right). Values range from 12°C (yellow) to 15°C (dark brown).

To select the method that better fits the data set, a cross validation comparison was performed. The model with the lowest root mean square error is the one that was finally selected, Ordinary Kriging exponential was the selected model in this case.

Another factor involved in this kind of analysis is the time. Since the physical parameters vary not only along the space but also with the time, the amount of data collected by the WSN is so large that data processing troubles appeared frequently. Also, the level of analysis required increases a lot and demands training and skill working procedures.

**CONCLUSION.** Precision Viticulture has an increasing impact on the world-wide wine-growing sector because of the best management of the inherent variability, the best economic benefits and the reduction of environmental impact. So far very few decisions on vineyard management (canopy conduction, pruning, pest treatments or harvest) are made basing on individual plants. Any approach to decision support systems is more effective at the level of block or small zone than individual plant. But mapping should be no longer constrained to a collection and often outdated data collected from satellites that must be preprocessed to obtain useful results. A map showing the field variability improves a better understanding of data collected from a dense WSN enabling decision making in selecting the best strategy for crop management. The precision of the map will depend on the number of nodes and the reliability of the process.

The variability analysis would lead users to make on-the-go changes in sensor location within the canopy, replacement of the out-of-range devices and optimize the number of nodes improving the experimental WSN prototype design. Certain aspects concerning standard data communication and power supply of this kind of networks have being solved. Future advances in this field will include the improvement of the quality model that could be validated when harvesting quality data were integrated. Additional data to estimate plant water requirements could be used in further experiments.

## REFERENCES

- AKKAYA K., DEMIRBAS M., AYGUN R.S. 2006. The impact of data aggregation on the performance of wireless sensor networks, *Wireless Communications and Mobile Computing* (in press), Published online in Wiley InterScience ([www.interscience.wiley.com](http://www.interscience.wiley.com)) DOI: 10.1002/wcm.454
- AKYILDIZ F., SU W., SANKARASUBRAMANIAM Y., CAYIRCI E. 2002. *Wireless*

- sensor networks: a survey, *Computer Networks*, 38: 393-422.
- ARNO J., MARTINEZ-CASANOVAS J.A., RIBES-DASI M., ROSELL J.R. 2009. Review. Precision viticulture. Research topics, challenges and opportunities in site-specific vineyard management. *Spanish Journal of Agricultural Research* 7(4): 779-790.
- BRAMLEY R., WINTER E., PROFFITT T., LAMB D. 2006. Precision Viticulture: A New Era in Vineyard Management and Wine Production, *Winetitles Australia*.
- BRASA A.; MONTERO F. J.; DE JUAN J. A. (2001. El papel de la cubierta vegetal. Desertificación y Agricultura. Ediciones Mundi-Prensa, Madrid, 163-176.
- BRASA A., MONTERO F.J., MONTERO GARCIA F., ALÍA J.M., VERDEJO C. 2006. Land-use planning by using Geographic Information Systems for Grape-growing Zoning in Valdepeñas, Spain, *World Congress: Agricultural Engineering for a Better World*, Bonn 3-7 September 2006, 49-50.
- BROOKE T., BURREL J., 2003. From Ethnography to Design in a Vineyard, *ACM 1-58113-728-1 03/0006 5.00*.
- BURRELL J., BROOKE T., BECKWITH R. 2004. Vineyard Computing: Sensor Networks in Agricultural Production, *IEEE Pervasive Computing*, 3 (1): 38-45.
- CAMILLI A., CUGNASCA C.E., SARAIVA A.M., HIRAKAWA A.R. CORREA P.L.P. 2007. From wireless sensors to field mapping: Anatomy of an application for precision agriculture, *Computers and Electronics in Agriculture*, 58: 25-36.
- CERPA A., ELSON J., ESTRIN D., GIROD L., HAMILTON M., ZHAO J. 2001. Habitat monitoring: application driver for wireless communications technology. In: *Proceedings of ACM SIGCOMM Workshop on Data Communications, Latin America and the Caribbean*.
- CLAY, D.E., CHANG, C., CARLSON, J., MALO, D., CLAY, S., ELLSBURY, M., 1998. Systematic evaluation of precision farming soil sampling requirements. In: *Proceedings of the 4th International Conference on Precision Agriculture*, St. Paul, MN. American Society of Agronomy, Madison, WI, pp. 253–266.
- COOK, S.E., BRAMLEY, R.G.V. 1998. Precision agriculture: Opportunities, benefits and pitfalls, *Australian Journal of Experimental Agriculture*, 38: 753-763.
- CROSSBOW 2007. Crossbow Home Page <http://www.xbow.com> (accessed July 18, 2007).
- ESRI 2009. Introduction to ArcGis 9 Geostatistical Analyst. ESRI. Available at: [www.esri.com](http://www.esri.com). Accessed 11 December 2009.
- NSC. 2001. Injury Facts Online. Itasca, Ill.: National Safety Council.
- HIDALGO L. 2002. Tratado de viticultura general. Ediciones Mundiprensa. Madrid.
- IEEE, 2003. Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). IEEE Standard 802.15.4. The Institute of Electrical and Electronics Engineers Inc., 345 East 47th Street, New York, USA.
- KRAVSEHNKO A., BULLOCK D. 1999. A comparative study of interpolation methods for mapping soil properties. *Agronomy Journal*, 91: 393–400.
- LAMB D.W., BRAMLEY R.G.V. 2001. Managing and monitoring spatial variability in vineyard variability. *Natural Resource Management* 4, 25-30.
- MCKINION J. M., TURNER S. B., WILLERS J. L., READ J. J., JENKINS J. N., MCDADE J. 2004. Wireless technology and satellite internet access for high-speed whole farm connectivity in precision agriculture, *Agricultural Systems*, 81: 201-212.
- MEIER, U., 1997. Growth stages of mono- and dicotyledonous plants: BBCH-

- Monograph Blackwell Science, Berlin , Vienna , a.o., pp 622
- MONTERO F.J., BRASA A. 2005.. Land and Water Use Management in Vine Growing by Using Geographic Information Systems in Castilla-La Mancha, Spain, *Agricultural Water Management* 77: 82–95.
- MORAIS R., FERNANDES M. A., MATOS S. G., SERODIO C., FERREIRA P.J.S.G., REIS M.J.C.S. 2008. A ZigBee multi-powered wireless acquisition device for remote sensing applications in precision viticulture. *Computers and Electronics in Agriculture*, 62: 94–106.
- PVA 2007. Precision Viticulture Australia Home Page <http://www.pvaaustralia.com.au> (accessed June 19, 2007).
- SMART R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *American Journal of Enology and Viticulture* 36: 230-239.
- TAYLOR, J.A. 2004. Digital Terroirs and Precision Viticulture: Investigations into the application of information technology in Australian vineyards. PhD Thesis, Australian Centre for Precision Agriculture, Faculty of Agriculture, Food and Natural Resources, The University of Sydney, New South Wales, Australia.
- USDA 2003. Keys to Soil Taxonomy, by Soil Survey Staff, United States Department of Agriculture, Natural Resources Conservation Service, Ninth Edition, 2003, Washington, USA.
- WOLLENHAUPT N.C., MULLA D.J., CRAWFORD C.A.G. 1997. In: Pierce, F.J., Sadler, E.J. (Eds.), *Soil Sampling and Interpolation Techniques for Mapping Spatial Variability of Soil Properties: The State of Site-Specific Management for Agriculture*. American Society of Agronomy/Crop Science Society of America/Soil Science Society of America, Madison, WI, pp. 19–53.
- WANG N., ZHANG N., WANG M. 2006. Wireless sensors in agriculture and food industry—Recent development and future perspective. *Computers and Electronics in Agriculture*, 50: 1-14.
- WORLD METEOROLOGICAL ORGANIZATION 2008. Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, 7<sup>th</sup> edition, Geneva.