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ENVIROMENTAL AGRONOMY – CYCLE XX

Department of Environmental Agronomy and Crop Science

***An application of agrometeorology: irrigation water
management in maize***

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31st January 2008

Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Alessandra Bonamano, 31st January 2008

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*To my Dad who is living
everlasting seasons in the
Heaven...*

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SUMMARY

Irrimanager is a *model* for *simulation* and evaluation of *irrigation scheduling*. The model performs the soil water balance and it is a multi-modal service because the irrigation advice can be in a internet (web page) or mobile way (txt).

This thesis reports on the use and validation of the model using independent data sets relative to meteorological data and phenological observation in order to validate in particular the last information given by the model to help the farmers. Version 1.1 and version 1.2 were used in maize crop in the Veneto Region.

Meteorological data's analysis demonstrated at local area the same climate change of the global area and in particular the anomalous trend of the precipitation during the summer season which made the crops more needed of water to avoid the losses caused by stress management. On the other hand the *phenological* observations, coming from a *Network* in the Veneto region, were used to analyse the answer of the crops to the climate change.

In fact, starting from these both records available meteorological and phenological data, the validation was carried out in 2006 and 2007, comparing simulated values of soil moisture and phenological stages with the measured ones.

The validation of the model was performed also using an arid scenario: maize crop in Victoria, West Australia, in 2007, comparing the output with that ones coming from a similar easy water balance model, created by the Department of Primary Industry of Kyabram. The results showed the good performances of the model in Legnaro in 2006 with both versions and also in Australia, not significant correlation was founded in Legnaro in 2007 with last version. These results support the importance how the agrometeorology science, multidisciplinary science, can play a fundamental role in the modern agriculture.

Key words: Model validation; Irrigation scheduling, Maize, Phenological network

Riassunto

Irrimanager è un model per la simulazione del consiglio irriguo. Il modello calcola il bilancio idrico ed è supportato da un servizio *multimodale* perché il consiglio irriguo è disponibile on line o attraverso un servizio di messaggio di testo sul telefono mobile.

Questa tesi ha come oggetto l'uso e la validazione di tale modello usando dati scientifici relativi a data set meteorologici e fenologici con il fine ultimo di validare l'informazione finale che arriva all'agricoltore dalle simulazioni del modello. La versione 1.1 e la versione 1.2 sono state utilizzate in Legnaro, nella coltura di mais. I dati meteorologici analizzati dimostrano che anche a scala locale gli stessi cambiamenti climatici vengono ritrovati ed in particolare nella distribuzione anomala della pioggia durante la stagione estiva: le colture così richiedono fabbisogni di acqua maggiori per evitare le perdite di produzione dovute da stress idrico.

Dati fenologici provenienti dalla rete della regione Veneto sono stati usati per analizzare la risposta delle piante ai cambiamenti climatici. Tali dati hanno permesso così la validazione del modello per valori di umidità del suolo e fenologia nel 2006 e nel 2007, comparando valori simulati con quelli sperimentali raccolti in campo. La validazione del modello è stata anche effettuata nella coltura di mais in West Australia, nello stato di Vittoria, nel 2007 comparando i risultati ottenuti da un modello di bilancio idrico, simile ad Irrimanager, creato dal Dipartimento dell'Industria Primaria di Kyabram. Il modello ottime abilità nel simulare valori di umidità del suolo nel 2006 con entrambi le versioni, ma non nel 2007 non è stato così. Soddisfacenti invece sono stati i valori della simulazione degli stadi fenologici per entrambi gli anni oggetto di studio. Questi risultati dimostrano alla luce dei cambiamenti climatici l'agrometeorologia sia una scienze multi – disciplinare che giochi un ruolo di fondamentale importante nell'agricoltura moderna.

Parole chiave: pianificazione irrigazione, modello di bilancio idrico, mais, rete fenologica, cambiamenti climatici

Chapter 1

GENERAL INTRODUCTION

1. Background

Agrometeorology, abbreviated from agricultural meteorology, puts the science of meteorology to the service of agriculture in its various forms and facets, to help with sensible use of land, accelerate production of food, and of course to avoid the irreversible abuse of land resources (Smith, 1980). It is also defined as the science investigating the meteorological, climatological and hydrological conditions significant to agriculture, owing to their interaction with the objects and processes of agricultural production (Molga, 1962). Agrometeorology also encompasses *biometeorology*, defined by the International Society of Biometeorology (ISB) as “an interdisciplinary science dealing with the application of fields meteorology and climatology to biological systems” (Hoppe, 2000). The general scope includes all kinds of interactions between atmospheric processes and living organism (plants, animals and humans): Thus, there are three sub-branches of biometeorology: plant, animal and human (Hoppe, 2000). The domain of agrometeorology is the plant and the animal sub-branches; the human branch remaining outside the scope of agrometeorology.

Agrometeorology on the contrary as someone is usual to define is not a “young science”. In an Italian Agricultural Miscellanea handbook of 1779, now kept at the national library “Marciana” of Venice (Italy), there is a confidential letter of a university professor of Padova to a his friend, located in Verona, in which a detailed description of the weather’s influence on wheat’s yield is reported. In particular, daily rainfall and temperature data, starting from 1730 until 1775 were studied in order to analyse how the weather affected the yields during the observed periods. The same author finished his letter affirming how his study can be considered a of the application of the meteorology on agriculture, however the definition of agrometeorology is not provided. It’s necessary waiting for the 1920 s, when it was a working branch of *climatology*. In the years following 1950 it developed widely to an independent science. In this process, agrometeorology has not only gained a vast knowledge of the influence of meteorological conditions on damage prevention for plants and livestock, but also evolved and generated new knowledge which holds great practical use in agriculture.

Agrometeorology is an interdisciplinary science in which the main disciplines involved are atmospheric- and soil-sciences, which are concerned with the physical environment and plant science and animal science.

The interdisciplinary nature of agrometeorology however, is both its greatest strength and its greatest weakness (Hollinger, 1994). The strength is obtained from an agricultural meteorologist’s understanding of the interactions of physical and biological worlds. The weakness is due to the political reality that agricultural meteorology is not fully appreciated by more traditional practitioners of the physical and biological sciences. Though interdisciplinary in nature, agrometeorology is a

well defined science, with a set approach in theory and methodology. Its subject matter links together the physical environment and biological responses under natural conditions.

An *agro meteorologist* applies all relevant meteorological skill to help the farmers make the most efficient use of their physical environment in order to improve agriculture production (both in quality and quantity), but at the same time in order to maintain the sustainability of their land and resources (Bourke, 1968). For optimum crop growth, specific climatic conditions are required. Agrometeorology thus becomes relevant to crop production because it is concerned with the interactions between meteorological and hydrological factors on the one hand, and agriculture in the widest sense including horticulture, animal husbandry and forestry, on the other.

The field of interest of an agro meteorologist extends from the soil surface layer, to the depth down to which the roots penetrate. At the same time, their interest is in the layer of air near the ground, to the highest levels in the atmosphere. As new research uncovers the secrets of meteorological phenomena, there is increasing interest in remote sensing and interactions between oceans and the atmosphere in shaping seasonal conditions. Agrometeorology offers practical solutions for harnessing climate potential and for protection against, or avoidance of climate-related risks, and at the same time has two important roles: strategic and tactical. The first is involved in the assessment of long term utilization of natural resources in the development of crop diversity, and the second is concerned with the short term and field-scale decisions (Rijks et al., 2000).

Of the total annual crop losses in world agriculture, a large percentage is due to direct weather effects such as a drought, flash floods, untimely rains, frost, hail and storms. Losses in harvest and storage, as well as those due to parasites, insects and plant diseases are very highly influenced by the weather (Mavi, 1994). When specifically tailored weather information is available to the needs of agriculture, it contributes toward making short-term adjustment in daily agriculture operation, which minimize losses resulting from adverse weather conditions and improves the yield and quality of the agriculture products. Seasonal climate forecast can play an important role in shaping economic policies of governments, in fact with a forecast of a major drought, economic growth would be less than expected; by taking serious note of the forecast, monetary policy could be relaxed to maintain growth targets (White, 2000).

Other applications of agrometeorology are found through improvement in techniques based on sound interpretation of meteorological knowledge: these include irrigation and water allocation strategies like shelter from wind and cold, shade from heat, antifrost measures, anti-erosion measures, soil cover and

mulching, climate control in storage and transport; and efficient use of herbicides, insecticides and fertilizers. Agro meteorological models can also be used in efficient land-use-planning; determining suitable crops for a region: risk analysis of climatic hazards and profit calculations in farming; production of harvest forecast, the adoption of the farming methods and the choice of effective farm machinery.

2. Need for the study

The availability of a proper meteorological and agrometeorological database is a major pre-requisite for studying and managing the processes of agricultural and forest production. Historical data and observations during the growing season play a critical role in increased applications of crop model and model generated output by farmers, consultants and other policy-and decision makers. The major priority is to build a database of meteorological and phenological, soil and of course agronomic information. The acquisition of agro meteorological data and their quality control and management are important components that will make the information valuable to agro meteorological research and also to operational programs.

The most important development for science in general and for agro meteorology is the rapid advances in electronic technologies, and how this application on the capacity of computers and communication and also measurement technologies. In agro meteorology, in which a vast amount of atmospheric data must be linked with complex sets of biological data, the availability of data in a uniform file format and the vanishing of data processing limitations result in a strong momentum for research. For these reasons agro meteorological models have many potential uses for answering questions in research, crop management and policy and for these reasons a major area for future research is the response of environmentally sensitive agricultural practises to weather events (De Pauw and al., 2000).

Another example, may be the need to obtain a better understanding of the role of the weather and the fate of agriculture chemicals during application, and their persistence, and also the moment after their application and their effect on natural organisms. One of the most important current problems of human kind is global warming and its impact on the environment, water resources, agriculture and human health. Agro meteorology, in this case, plays a leading role in the assessment of climate change, its impact on the biosphere and adaptation strategies to increasing climate variability and climate change.

Climate change is defined as “Any long term substantial deviation from present climate because of variations in weather and climatic elements”.

The causes of climate change are : 1)The natural causes like changes in earth revolution, changes in area of continents, variations in solar system, etc. 2)Due to human activities the concentrations of carbon dioxide and certain other harmful atmospheric gases have been increasing.

On the other side one of the most relevant effect of the climate change is that crop production is highly dependent on variation in weather and therefore any change in global climate will have major effects on crop yields and productivity, and in particular on the yield losses and water requirements.

Proper understanding of the effects of climate change helps scientists to guide farmers to make crop management decisions such as selection of crops, cultivars, sowing dates and irrigation scheduling to minimize the risks. In recent years there has been a growing concern that changes in climate will lead to significant damage to both market and non-market sectors. The climate change will have a negative effect in many countries. But farmers adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies will help to ease the impact. The variability of our climate and especially the associated weather extremes is currently one of the concerns of the scientific as well as general community.

The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models, *agrometeorology* and the concerns of the society.

As climate change deals with future issues crop simulation models proves a more scientific approach to study the impact of climate change on agricultural production and world food security compared to surveys.(Murthy, 2004)

Increasing environmental, population and economic pressures are creating difficulties in solving agricultural pest and diseases management problems. This will require improved analysis of the weather to develop new pest management strategies and techniques. Agro meteorologist trained in weather pest and weather diseases relationship and in the basic of pest management disciplines needs to play a key role in developing pest and disease management strategies (Strand, 2000).

The acquisition of knowledge and skills should be viewed as a continuous process through a professional career (Lomas et al., 2000). The need for continued training in agro meteorology was demonstrated by a survey on education and training requirements by WMO (Olufyao et al., 1998). In some countries, national, meteorological and hydrological services do not exist and they do not have adequately trained personnel.

In the same academic setting there is a need for creative educational programs and also there is a need of professional persons dedicated to these topics. But only few professionals are being trained in this science because there are not independent programs or departments in the universities and the money for such projects is limited. Farmers also need to learn how to take their daily decision making, and at the same time they need to learn how to better use the weather

driven models. So research programs are needed to improve the quantity and the reliability of forecasts and show how these forecasts can be used to improve decision making. Then there is the need to transfer these findings to agriculture producers.

Information has value when it is disseminated in a such way that end users receive the maximum benefit from applying it (Weiss et al., 1989). Areas of agriculture expertise that have prospered throughout the years are those with a informative product that is appreciated and used by farmers. The opportunity for agro meteorological services will grow dramatically. The importance and economic benefits of agro meteorologist is to educate agricultural producers to use weather data in various management decisions. This science has a number of perspectives and applications, in fact, with improved new doors are opened to agrometeorology that were not available before. The future is offering a challenge for the development of applications, risk analysis and forest model and assessment of production under the actual climate change.

3. Aims of the study

The aims of the study are to:

1. Improve understanding of the importance of the high-quality climate and agricultural records for agricultural purposes (data, trends and statistic analysis), also the importance of new data sources for operational agrometeorology.
2. Using data coming from more than one research project as a start to study the right water management in the modern agriculture especially on the *Zea Mays*
3. testing and valuating a easy water balance model, created as a irrigation support to the farmers in Italy
4. using the results coming out of this research to give the better quality of the irrigation management information.

This leads onto describing the **hypothesis** associated with this study:

the hypothesis: is the efficacy of the agrometeorological information to improve the crop productions and to make a sustainable agriculture, by testing a simple water balance model and using, at the same time, some main meteorological and phenological records collected during the 3 years of the project.

4. Thesis overview

These thesis comprises 6 chapters (Fig. 1)

Chapter 1 provides a general introduction and overview of the thesis and a literature review, with an overview of current knowledge and understanding in relation to the aims of the agrometeorology science.

Chapter 2 presents an overview of the management of the meteorological dataset, their validation and quality but also the problem of missing data and the importance of their rebuilding in the trend analysis.

Chapter 3 presents the Phenological Network of maize in the Veneto during 2005-2007 and the application of these records to analyse relationship between temperature and phenology and to validate the phenological subroutine of the water balance model in Legnaro (Padova, Italy).

Chapter 4 is the description of the main instrument of this thesis, the water balance simulator called IRRIMANAGER . In this section, in fact, a short description of the simulator is provided in order to explain how this easy model can play an important role in a farming management . Also the new side of this service is provided in this chapter: in particular its web (IRRIWEB) and mobile phone side (IRRISMS).

Chapter 5 presents Irrimanager' s use and validation in the experimental site in Legnaro, North East of Italy but also in Kyabram, Western Australia, where the model was used and compared with a similar one applied in a maize field.

In Chapter 6 a general summary of the key findings and outcomes arising from the study are presented, in terms of identification how, starting from meteorological data available, it is possible improving on a valid support to the farmers. This is then followed by suggestion for future work and final conclusion to complete the thesis.

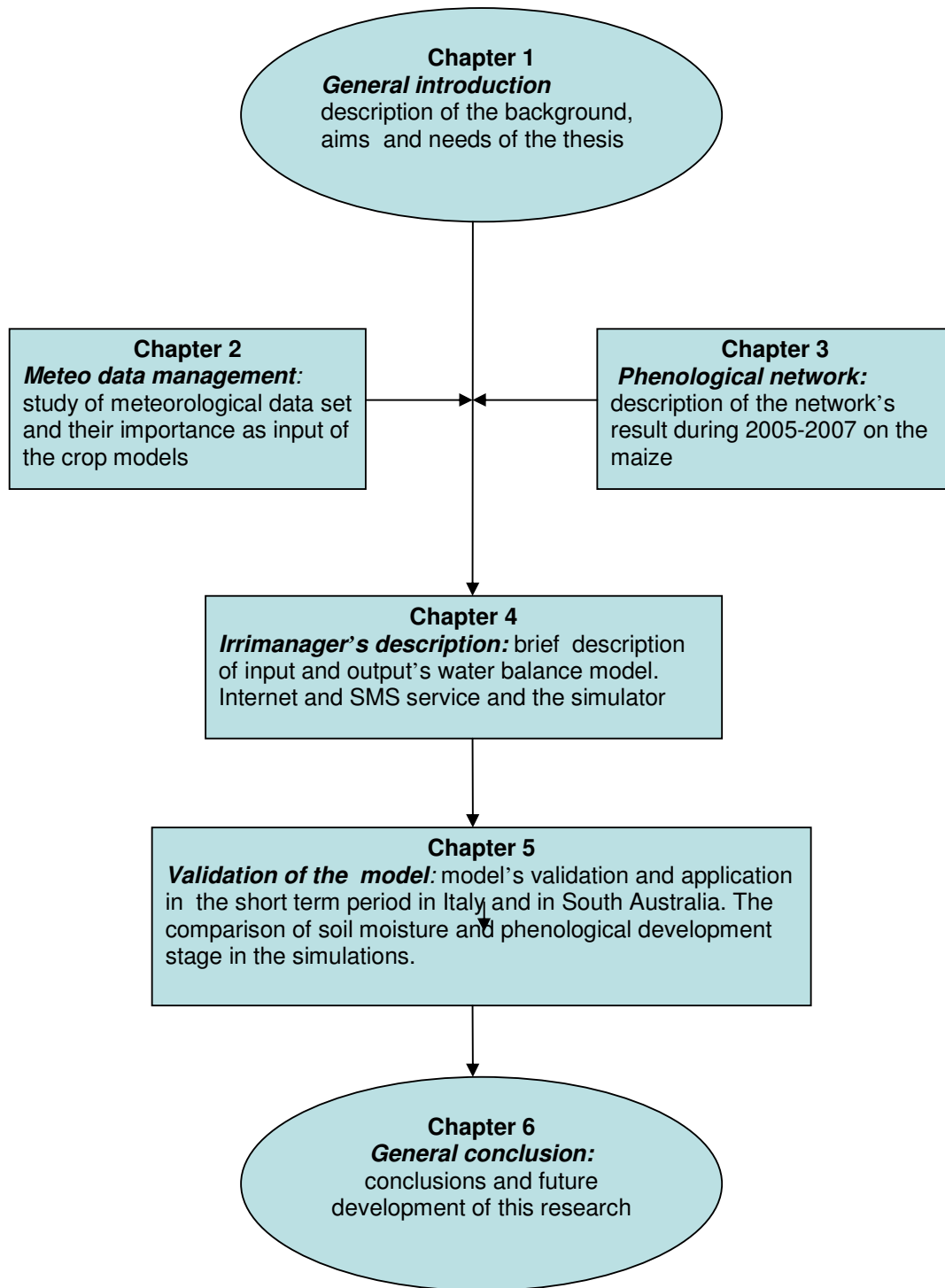


Fig. 1 - Flow chart of the thesis

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Chapter 2

METEOROLOGICAL DATA MANAGEMENT

1. Introduction

Computer models, in general, are a mathematical representation of a real world system (Mize and Cox, 1968). In reality, it is impossible to include all the interactions between environment and the modelled system in a computer model. In most cases, a computer model, therefore, is a simplification of a real-world system. A model might include many assumptions, especially when the information that describes the interactions of the system is inadequate or does not exist.

Weather is one of the key components that controls agricultural production. In some cases, it has been stated that as much as 80% of the variability of agricultural production is due to the variability in weather conditions, especially for rainfed production systems (Petr, 1991). Weather has a major impact on plants as well as pests and diseases.

It is important to summarize the potential effect of the different weather variables on crop growth and development. The most critical agrometeorological variables associated with agricultural production are precipitation, air temperature and solar radiation.

These weather variables are key input variables for the simulation models and they can be defined as primary weather input variables but there are also some other input variables, including wind speed, relative humidity or evapotranspiration that can be defined as secondary weather input variables.

Critical issues are the *availability* and the *quality* of weather data to be able to run crop simulation models for a certain location or for particular application, because they can be the main source of errors causing consequentially, errors also in the output.

In this chapter an analysis of weather dataset of Legnaro (1953-2007), the experimental site of the object of this thesis was carried out in order to obtain correct input for the water balance simulation and at the same time in order to study the potential impact of climate change on a local area. Meteorological data of Legnaro in fact were used to prepare the meteorological input file for Irrimanager in 2006 and 2007 and the total data set was used to study the trend of the main weather data.

The variability of our climate and especially the associated weather extremes is currently one of the concerns of the scientific as well as the general community (Climate Research Committee, 1995).

2. Materials and Methods

2.1 Meteorological station

Legnaro (45° 20' 32"N; 11° 57' 58"E, 11 altitude) has provided of an own meteorological station from 1953.

The station belongs to Arpav, the Regional Agency for Protection and Environment in Veneto Region and it is situated in the university farm, in a position close to the crops object of this study. Arpav has more than 200 different meteorological station in Veneto and Legnaro is one of the agrometeorological station because it is provided of more measures than the classic meteorological ones. Starting from 1953 daily rainfall, temperature and relative humidity data are available, after 1979 also global radiation and wind speed, in this way it was possible the reconstruction of evapotranspiration with Hargreaves formula.

Evapotranspiration after 1979 ,however, Is calculated with Penman Monteith formula (Penman, 1948).Therefore, hourly rainfall data are available only after 1992.

2.2 Check, validation and rebuild of meteorological records

All the measured data were checked and validated in order to study their trend during the period 1963 – 2007. Therefore any missing values were rebuild..The software used in the management of these data was Climatica.

Climatica is a weather program developed by Prof. Danuso of University of Udine, Italy. In 2003 It is composed by Climack, a stochastic weather generator, and SEmOla 4, a graphic and statistical tool. Climatica works with a Windows ambient, it has got an user graphic interface and it is free source, available on internet web page:

http://www.dpvta.uniud.it/~Danuso/docs/Climatica/Climatica_Home.html

2.3 Statistical analysis

Statistical analysis of rainfall, temperature and evapotranspiration were carried out in order to analyze the trend of the main weather variables in response to the climate change. Statistical analysis of monthly rainfall, temperature and evapotranspiration were carried out in order to analyze the trend of the main weather variables in response to the climate change. The trend was study not only yearly but in particular during July, August and September: in fact for maize

crop, object of this study, these months are the most critical: because any stress, during the crucial phenological stages can provoke significant losses in the yield.

3. Results

3.1 Check, validation and rebuilding of data

Table 1 reported a short summary of the total dataset of Legnaro starting from 1963 until 2007.

A good check was carried out and many errors were found in the temperature because values of minimum and maximum were inverted.

Only two Missing data were found only in the relative humidity and reconstructed with neural network method of Climatica.

3.2 Rainfall, temperature, global radiation and evapotranspiration's trend

Annual trend of rainfall had a not significant decreasing (Fig.1) whilst significant one were founded during the summer season in particular in August, decreasing trend but not relevant were also founded in July and September (Fig. 2, 3 and 4)

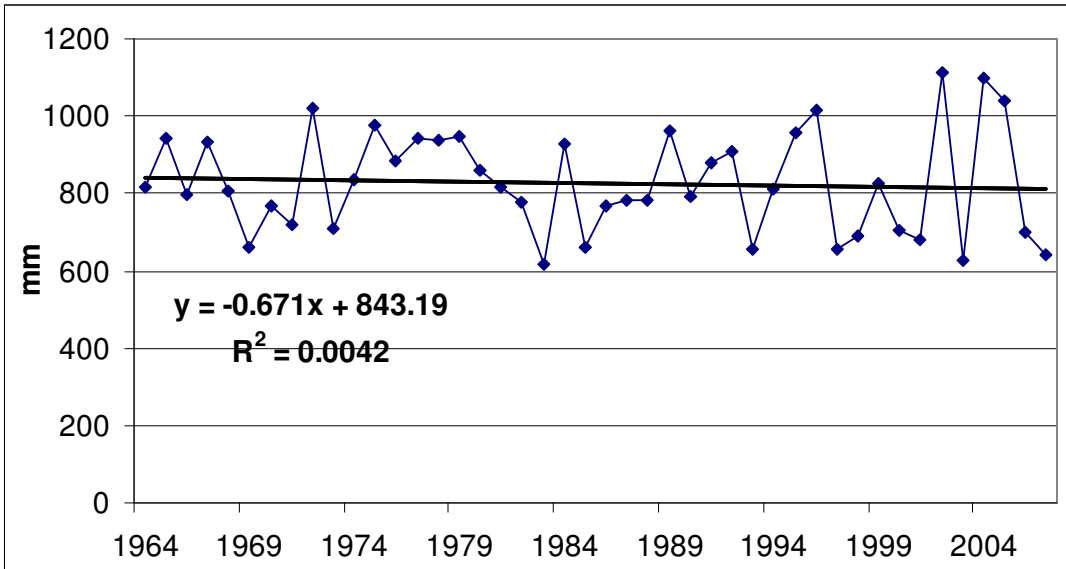


Fig.1 Annual rainfall total amount

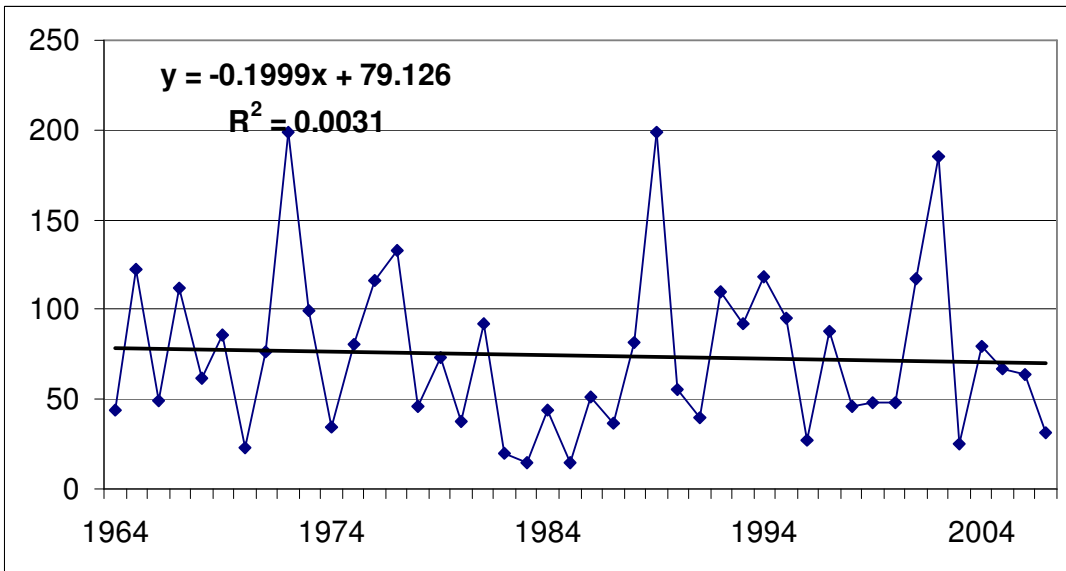


Fig.2 July rainfall total amount

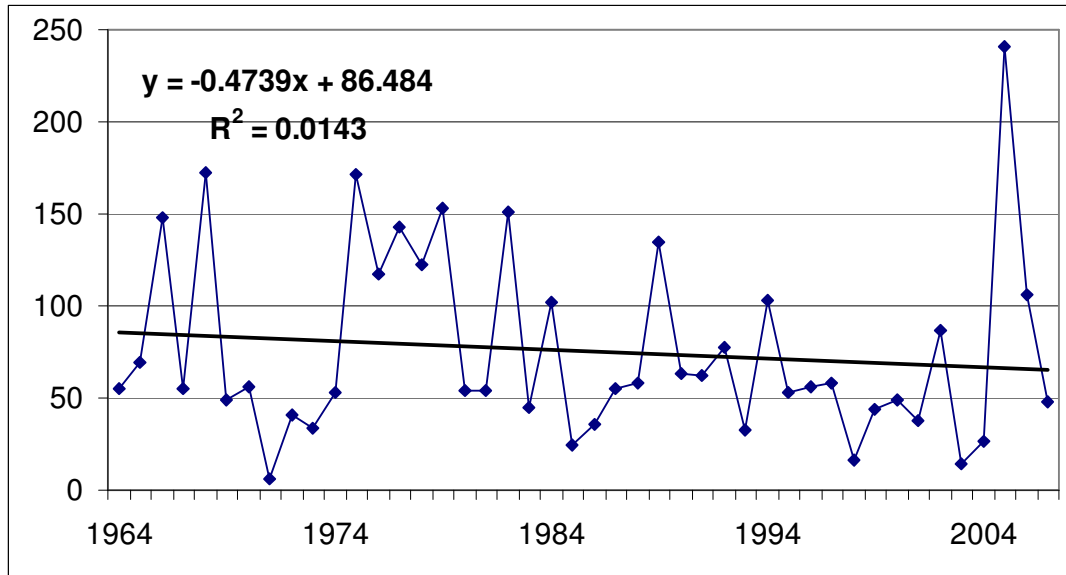


Fig.3 August rainfall total amount

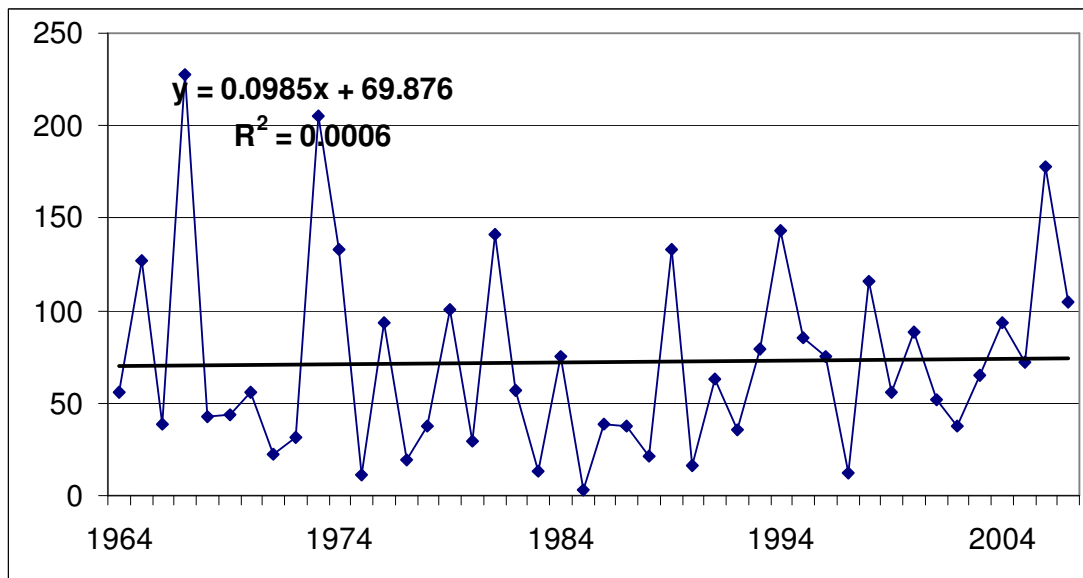


Fig.4 September rainfall total amount

Maximum and Minimum temperatures are increasing on annual basis (Fig. 5) but the same situation was also founded during the 3 considered months in fact July, August and September had decreasing values (Fig. 6,7 and 8).

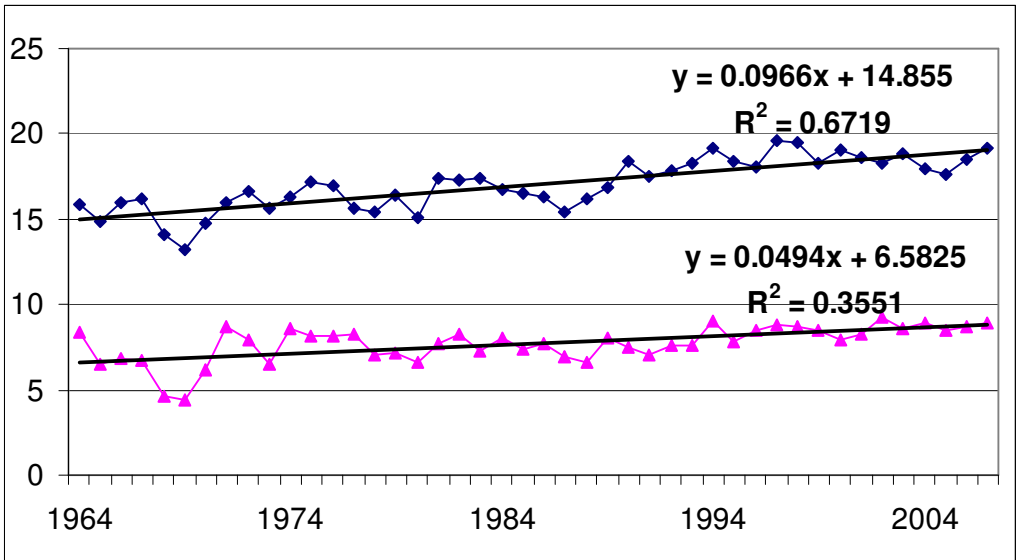


Fig. 5 Annual average minimum and maximum temperature

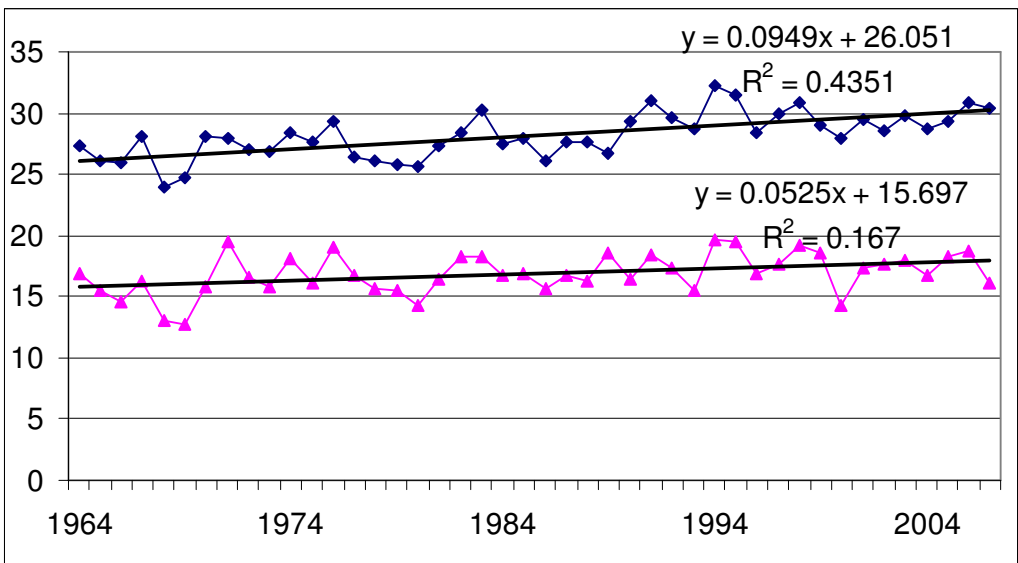


Fig. 6 July average minimum and maximum temperature

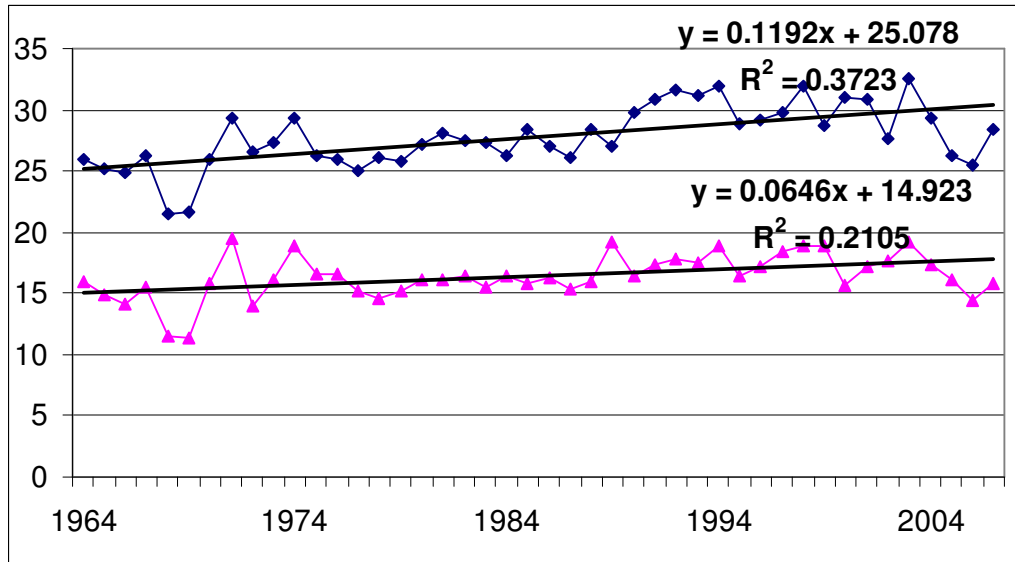


Fig. 7 August average minimum and maximum temperature

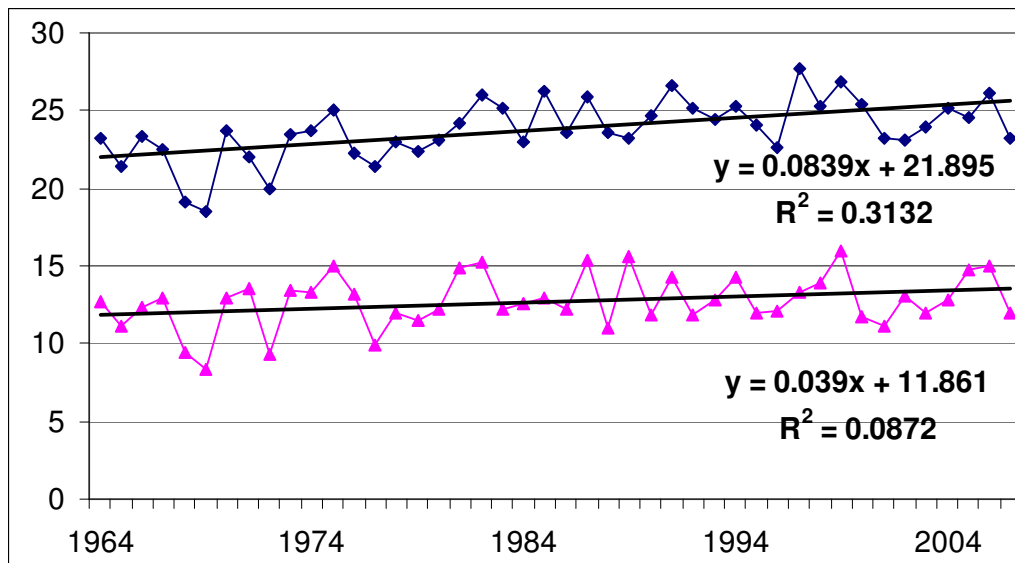


Fig. 8 September average minimum and maximum temperature

Solar radiation has an increasing annual trend (Fig. 9). Note that during the last years an anomalous trend of this variables is showing not only in Legnaro but also in other meteorological station of Arpav network. This is probably due to a anomaly of solar radiation sensor. It's important to remember how this values can be affected the evapotranspiration values because in the majority of the case evapotranspiration is not measured but easily derived from other meteorological values using formula.

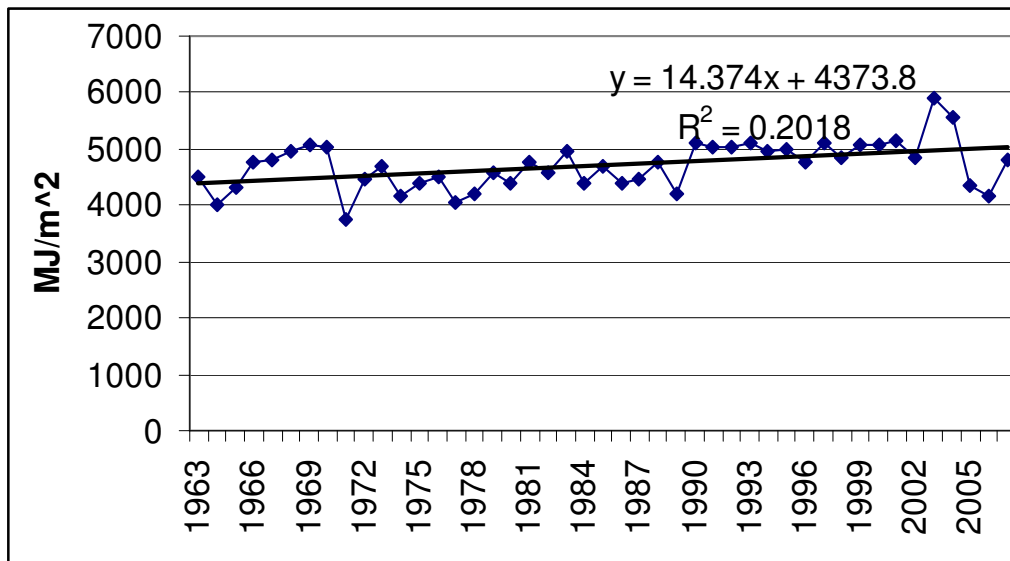


Fig. 9 - Annual total solar radiation

In fact in Legnaro evapotranspiration is computed from FAO Penman Monteith formula.

Evapotranspiration had significant decreasing in the annual trend: in fact the reduction of rainfall especially during the summer season affects the balance of evapotranspiration during all the year.

4. Conclusion

Data are of good quality when they satisfy and implied needs. The purpose of quality management ensure that data meet requirements for the intended application, at a minimum practicable cost. Good data are not necessarily excellent, but it is essential that their quality is known and demonstrable.

Results obtained from checked data in the historical dataset in Legnaro, Italy, the experimental site of this thesis, demonstrated that the check on the data set has been necessary and useful at the same time to correct some errors in the old records.

Analysis carried out on rainfall, temperature, solar radiation and calculated records demonstrated a real climate change on local area that is the same on the global one. In particular it is important the analysis of rainfall's trend and its increasing

especially during the summer season that makes the irrigation a obliged instrument to avoid the crop stress.

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Chapter 3

A PHENOLOGICAL NETWORK IN THE VENETO REGION

1. Introduction

Phenology is *art of observing of biological phases, both plants and animals, during the year* (Lieth, 1974) and so, according this definition, it should be more correct the term of “phyto-phenology” for this study. All of these events are sensitive measures of climatic variation and change, are relatively simple to record and understand, and are vital to both the scientific and public interest.

Phenology can be used as a predictor for a variety of processes and variables of importance at local to global scales. Phenology modulates the abundance and diversity of organisms, their inter-specific interactions, their ecological functions, and their effects on fluxes in water, energy, and chemical elements at various scales.

The observed phases span the whole vegetation period starting in early spring proceeding to spring coming to summer. The plant development is driven mainly by weather and other environmental factors. The different phases can be used to define the start and end of vegetation cycles and to separate natural seasons.

Phenological phases reflect among other things the environmental characteristics of the climate in the region where they occur. Consequently, long series of phenological observations may be used for the detection of climate variability or climate change.

The actual timing of these events is also of importance for issues in our everyday life (<http://topshare.wur.nl/cost725/70902>):

- *Education*: involving school children and the public in scientific research by very cheap and easily accessible means (plants can be observed everywhere without any tool apart keen interest, some knowledge on plant identification and some basic rules), would bring a closer connection with nature.

- *Human Health*: providing pollen information for sensitive groups.

- *Agriculture*: providing pheno data as input for crop models, and for the timing of management activities.

- *Biodiversity / Ecology*: Assessing the impacts of extreme events, species interaction, migration of plants to new zones (e.g. to higher altitude or latitude).

- *Gardening*: Giving information to the public on planning activities like pest control.

- *Increasing environmental awareness*: Informing the public on environmental issues like climate change and its effects on vegetation.

- *Tourism, Recreation & Sports*: Giving information on phenomena or events that potentially can interest people (e.g., in Austria, bike-tours on cherry-flowering or apricot-flowering are organised).

Phenological data and models are useful in agriculture, in fact the observations collected in this work also helped the phenological validations of the water balance model, Irrimanager, because the phenological developments are closely connected with plant's evapotranspiration and the soil water balance.

In most European countries, phenological data are collected or have been collected in the past over several decades. Within these different phenological programmes, the vegetation cycle of plants is usually observed (native, agricultural plants and fruits) and in some countries also cyclical animal behaviour like bird migration, egg laying or insect appearance etc.

At local scale a Phenology Network in the Veneto Region is currently being designed and organized to engage some partners, the most of them on voluntary basis. The initial phase in spring 2005 established a regional -scale network focused on phenological observations of a few regionally appropriate main crops of this region. The phenology was coded according to the BBCH General Scale (Meier, 2001)

Veneto's phenological network aims to improve monitoring, assessment and prediction of climate-induced phenological changes and their effects in Veneto. Its overall objective is to increase the efficiency, added value and use of phenological monitoring and research and to promote the practical use of phenological data in Veneto in the context of global (climate) change.

The main objective in this study was to validate the phenological module of the water balance simulator used in this thesis, using phenological data coming from the network. At the same time this chapter studies the temperature's accumulation in different locations of Veneto and then the relationship between BBCH stages and temperature.

The network is also available on line on a special link so the farmers can check the real stage development.

The results of this work were presented and discussed at the Agro-Meteorology's session of the European Meteorological Society Annual conference (2006 and 2007) to inform other potentially interested actors of the whole network and to compare the results with the results come from the other existing network.

2. Materials and Methods

2.1 Partners

The network was born in 2005. At the beginning it was born from a common consent among the Department of Environmental Agronomy and Vegetal Production, University of Padova, Arpa Veneto, Regional Agency for Health Prevention and Environmental Protection, and two schools of High Agriculture schools' Network of Veneto region.

During the years of the project other important partners participated in the network with phenological records:

- Repros srl , a private society busy in agriculture experimentation, located close to Vicenza.
- Lison's Wine Syndicate located in Treviso 's province.

The network includes not only maize but also grapevine (with some international and national varieties), wheat and barley during the winter season.

It is based on a voluntary basis because only few money is destined in this research: the only strength is a synergy among the partners with a reciprocal exchange of scientific information or services (meteorological data, statistical analysis, lectures, training activities...)

2.2 Location

Veneto Region is situated in North East of Italy and it is composed by 56,4% of plain but also by 29,1% of mountain and by 14,5% of hills.



Fig.1 - Phenological Network in the Veneto Region (Italy) and seven site

The sites of phenological network for maize are uniformly scattered on the Veneto plain territory (Fig.1). In this way at least one site for each province and for each year is guaranteed even if there is no site in the mountain zone of Belluno because maize is not an important main crop in this part of the region.

The field sites are 7: Legnaro (Padova), San Stino di Livenza (Venezia), Noventa Vicentina (Vicenza), Bovolino di Buttapietra (Verona), Belfiore d'Adige (Verona) and Fiesso Umbertino (Rovigo) and Castelfranco Veneto (Treviso) (Tab.1).

<i>Location</i>	<i>Country</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Altitude (metre)</i>
Legnaro	Padova	45°21'N	11°58'E	12
San Stino di Livenza	Venezia	45° 41' 42"	12° 42' 54"	6
Castelfranco Veneto	Treviso	45° 40' 51"	11° 56' 18"	43
Noventa Vicentina	Vicenza	45° 17' 0" N	11° 32' 0" E	16
Fiesso Umbertino	Rovigo	44° 58' 0" N	11° 36' 0" E	9
Bovolino di Buttapietra	Verona	45° 21' 0" N	10° 56' 0" E	38
Belfiore d'Adige	Verona	45° 23' 0" N	11° 12' 0" E	26

Tab.1 - Network maize's locations in the Veneto region

2.3 Crop

Zea Mays was chosen in the network as one of the main crops of the Veneto. In fact the total cultivated area in Veneto is about 44200 ha and 29300 is cultivated with maize so it means that maize crop is more than half of total. (www.istat.it).

Two kinds of FAO class were used: 500 and 600. FAO class is maturity class index (Tab. 2) and they are different because each corn hybrid requires different specific number of GDD (Growing Degree Days) to reach maturity regardless of the number of days taken to accumulate them (www.fao.org).

500 and 600 FAO classes are however very close because only few days and few growing degrees day make the difference in reaching the harvesting time.

Location	2005	2006	2007
Legnaro - Padova	600	600	600
San Stino di Livenza - Venezia	500	500	-
Castelfranco Veneto - Treviso	600	600	600
Noventa Vicentina - Vicenza	600	500	500
Fiesso Umbertino - Rovigo	500	600	600
Buttapietra - Verona	600	600	600
Belfiore d'Adige - Verona	500	500	500

Tab. 2 - Locations and FAO class during the period 2005-2007

Different kinds of hybrids were used by the partners during the 3 years of the project:

- Costanza, Mitic, DK6530 (FAO class 600)
- PR34N43, DKC6040, DK6530 (FAO class 500)

Legnaro in 2005 didn't reach the harvesting development for a hailstorm (* in Tab. 2) during the month of July and the event destroyed totally the whole experimental field so the observations couldn't keep going.

San Stino di Livenza (- in Tab. 2) in 2007 was not present at the network because during the last year the experimentation in this place was not done from the private partner.

2.4 Phenological stages

The extended BBCH-scale is a system for a uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species. It results from teamwork between the German Federal Biological Research Centre for Agriculture and Forestry (BBA), the German Federal Office of Plant Varieties (BSA), the German Agrochemical Association (IVA) and the Institute for Vegetables and Ornamentals in Grossbeeren/Erfurt, Germany (IGZ) (AA.VV., 1997)

The decimal code, which is divided into principal and secondary growth stages, is based on the well-known cereal code developed by ZADOKS et al. (1974) in order to avoid major changes from this widely used phenological key. The abbreviation BBCH derives from Biologische Bundesanstalt, Bundessortenamt and Chemical industry.

The basic principles of the scale are:

- The general scale forms the framework within which the individual scales are developed. It can also be used for those plant species for which no special scale is currently available.

- Similar phenological stages of each plant species are given the same code.
- For each code, a description is given, and for some important stages, drawings are included.

- For the description of the phenological development stages, clear and easily recognised (external) morphological characteristics are used.

- Except where stated otherwise, only the development of the main stem is taken into consideration.

- The growth stages refer to representative individual plants within the crop stand. Crop stand characteristics may also be considered.

- Relative values relating to species- and/or variety-specific ultimate sizes are used for the indication of sizes.

- The secondary growth stages 0 to 8 correspond to the respective ordinal numbers or percentage values.

– Post harvest or storage treatment is coded **99**.

– Seed treatment before planting is coded **00**.

The entire developmental cycle of the plants is subdivided into ten clearly recognizable and distinguishable longer-lasting developmental phases. These principal growth stages are described using numbers from 0 to 9 in ascending order.

The principal growth stages are:

0 Germination / sprouting / bud development

1 Leaf development (main shoot)

2 Formation of side shoots / tillering

3 Stem elongation or rosette growth / shoot development
(main shoot)

4 Development of harvestable vegetative plant parts or vegetative propagated organs / booting (main shoot)

5 Inflorescence emergence (main shoot) / heading

6 Flowering (main shoot)

7 Development of fruit

8 Ripening or maturity of fruit and seed

9 Senescence, beginning of dormancy

If two or more principal growth stages proceed in parallel, both can be indicated by using a diagonal stroke (example 16/22). If only one stage is to be indicated, either the more advanced growth stage must be chosen or the principal growth stage of particular interest, depending upon the plant species. The principal growth stages alone are not sufficient to define exactly application or evaluation dates, since they always describe time spans in the course of the development of a plant.

Secondary stages are used if points of time or steps in the plant development must be indicated precisely. In contrast to the principal growth stages they are defined as short developmental steps characteristic of the respective plant species, which are passed successively during the respective principal growth stage.. The combination of the two numbers for the principal and the secondary stages, results in the two-digit code. The two-digit code is a scale which offers the possibility of precisely defining all phenological growth stages for the majority of plant species..

The BBCH-scales allow the comparison of individual codes only within one principal growth stage: an arithmetically greater code indicates a plant at a later growth stage. Sorting codes into numerical order therefore allows a listing in order of the stage of plant development. The time span of certain developmental phases of a plant can be exactly defined and coded by indicating two stages. For this purpose two codes are connected with a hyphen. Thus, for instance, the code 51–69 describes the

developmental phase from the appearance of the first inflorescence or flower buds until the end of flowering. This allows the computer-supported monitoring of crop stands.

For a uniform coding which covers the maximum number of plant species, it is necessary to use primarily phenological criteria rather than homologous or analogous stages. Thus, for instance, germination of plants from true seed and sprouting from buds are classified in one principal growth stage, the principal growth stage 0, even though they are completely different biological processes. In case of the BBCH-scales the descriptions are based on the actual characteristic features of the individual plant. If the scales are used for the definition of the development stage of a plant stand, the description should apply to at least 50% of the plants. Greater differences in the course of the development of different plant groups have to be taken into consideration for the description of the general scale (Meier, 2001)

2.5 The phenological observations

Phenological survey was conducted after a short learning meeting with the volunteers busy in the network. Each volunteer recorded the real phenological stages in a paper support and then suddenly communicated to the University for the real time information on Arpav web site (http://www.arpa.veneto.it/upload_teolo/agrometeo/index.htm). The project took 3 years.

In each field 28 plants were opportunely chosen after the seeding and they were marked with a label to permit the survey even after their maximum development. The same 28 plants were observed during the all growing season.

A detailed observation sheet (Fig 2) was prepared appropriately for this network and it contained not only information about the phenological stage, but also other main information about the crop:

- *Date* date of the effective observation
- *Location* the site of the field
- *Name of the person* the name of who makes the observation
- *Crop* name of the crop
- *Variety* variety and hybrid of the crop
- *Status of the crop stress or diseases* clearly shown by plants
- *Agronomic tillage* relevant tillage effectuated on the soil
- *Pesticides and fertilizers*: chemical product put on the plants or on the soil

site	Legnaro
name and surname	Alessandra Bonamano
crop variety	Maize
sowing's date	1 st April 2006
hybrid	Costanza, FAO class 600
observed stress	no
agronomic tillage	no
chemical products (pesticides or fertilizers)	no

Fig. 2 - An example of a detailed observation sheet, used in the Network

dd/mm/yy	plant n°1	Plant n°2	plant n°3	plantn°4	Plant n°5	plant n°6	plant n°7	plant n°8	plant n°9	plant n°10
01/04/2006	00	00	00	00	00	00	00	00	00	00
25/04/2006	09	09	09	09	09	09	09	09	09	09
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-

Fig. 2 An example of a detailed observation sheet, used in the Network

These observations were conducted weekly or every two weeks. They depended on the development stage because there are some stages that occur more quickly than other but to have a good data base it necessary having at least one observation for each main stage (Puppi et al, 1998).

At the end of the 3 years the observations were totally 229. With these records the Dummy Variables statistical analysis were used to investigate the significant differences among sites, FAO classes, hybrids and years.

Dummy variable, in fact, (also known as indicator or bound variable) is one that takes the values 0 or 1 to indicate the absence or presence of some categorical effect that may be expected to shift the outcome. Dummy variables may be extended to more complex cases. For example, seasonal effects may be captured by creating dummy variables for each of the seasons ([http://en.wikipedia.org/wiki/Dummy variable](http://en.wikipedia.org/wiki/Dummy_variable)).

2.6 Growing degree days or GDD

Growing degree days (GDD) are a heuristic tool in phenology. GDD are used by horticulturists and gardeners to predict the date that a flower will bloom or a crop reach maturity.

In the absence of extreme conditions such as unseasonable drought or disease, plants grow in a cumulative stepwise manner which is strongly influenced by the ambient temperature. Growing degree days take aspects of local weather into account and allow farmers to predict (or, in greenhouses, even to control) the plants' pace toward maturity (Lancashire et al., 1991).

GDD are calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature, T_{base} , (usually 10 °C).

As an equation:

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

Any temperature below T_{base} is set to T_{base} before calculating the average. Likewise, the maximum temperature is usually capped at 30 °C because most plants and insects do not grow any faster above that temperature. However, some warm temperate and tropical plants do have significant requirements for days above 30 °C to mature fruit or seeds.

10 °C is the most common base for GDD calculations, however, the optimal base is often determined experimentally based on the lifecycle of the plant or insect in question. In this study 8°C was used as a baseline for maize (Borin et al., 2001).

Applying this formula GDDs for each site of 3 years were calculated from 1st on March until 31st on September, assuming this interval like the general for the vegetative cycle starting from seeding to the harvesting time. With these records a average, starting from the seven site for the 3 years, was calculated.

Meteorological data came from the Arpav's meteo station closest to the phenological fields.

2.7 The phenological information on web

The phenological network is available on the link:

http://www.arpa.veneto.it/upload_teolo/agrometeo/index.htm.

Every week the web-page is updated to inform the farmer or who is interested in this topic about the development of the crops. The page is easy to understand and a simple click on the site of the maize's location allows to read the last phenological stage with the BBCH stage with a short description of the observation (Fig.3).

It is available also the figures of the plants during the main stage from the phenological atlas of M. Borin et al. 2002. The user can check the database of the last two years, estimating if the crops are reaching the stage earlier than in the past.

<i>Date rilievi</i>	<i>Stadio BBCH</i>	<i>Descrizione fase fenologica</i>	<i>Note</i>
17/04/2007	12	<i>Sviluppo delle foglie. Due foglie stese</i>	
24/04/2007	13	<i>Sviluppo delle foglie. Tre foglie stese</i>	
02/05/2007	14	<i>Sviluppo delle foglie. Quattro foglie stese</i>	
08/05/2007	14	<i>Sviluppo delle foglie. Quattro foglie stese</i>	
15/05/2007	31	<i>Allungamento del fusto. Un nodo distinguibili</i>	
22/05/2007	32	<i>Allungamento del fusto. Due nodi distinguibili</i>	
29/05/2007	33	<i>Allungamento del fusto. Tre nodi distinguibili</i>	
05/06/2007	34	<i>Allungamento del fusto. Quattro nodi distinguibili</i>	
12/06/2007	52	<i>Emergenza dell'infiorescenza. Il 20% infiorescenza è visibile</i>	
19/06/2007	61	<i>Fioritura. Prime antere visibili</i>	
26/06/2007	64	<i>Fioritura. Il 40% dei fiori è aperto</i>	
03/07/2007	68	<i>Fioritura. In fase finale</i>	
10/07/2007	69	<i>Fioritura. Fine della fioritura</i>	
17/07/2007	71	<i>Sviluppo del frutto. Inizio sviluppo del grano.</i>	
24/07/2007	71-81	<i>Inizio maturazione frutto.</i>	
31/07/2007	81	<i>Maturazione. Inizio fase maturazione. Il contenuto di sostanza secca è circa del 15%.</i>	
07/08/2007	81	<i>Maturazione. Inizio fase maturazione. Il contenuto di sostanza secca è circa del 15%.</i>	
14/08/2007	81	<i>Maturazione. Inizio fase maturazione. Il contenuto di sostanza secca è circa del 15%.</i>	
21/08/2007	82	<i>Maturazione. Inizio indurimento. Il contenuto di sostanza secca è circa del 30%.</i>	

Fig. 3 - Web page, starting by the first columns on the left: date, BBCH stage, short description of the development stage and the last box is for the agronomical details about the status of the crop

3. Results

Taking all the sites, from GDDs calculated each site was hotter in 2007 than 2006 and 2005 (Fig. 4). In 2007 GDDs reached 2500°C while in the other two years it reached only about 2200°C. In the 3 years the accumulation of active temperature was similar during the first three months and then there was a slight but continuous increase in the difference between 2007 and the other two years.

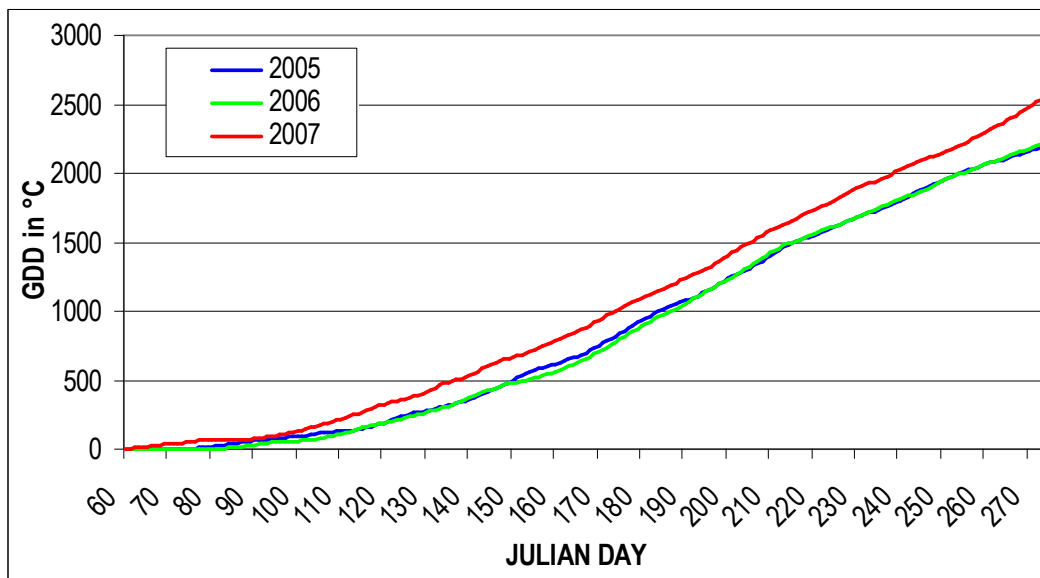


Fig. 4 - GDD's average of the 7 sites during 2005-2007

Among sites on the average temperature values, Noventa Vicentina was the hottest location and Fiesso Umbertino the coldest one. (Tab. 3)

<i>Location</i>	<i>2005</i>	<i>2006</i>	<i>2007</i>	<i>mean</i>
Legnaro	xxx	1940	1807	1874
San Stino di Livenza	2055	1849	xxxx	1952
Castelfranco Veneto	1787	1941	2131	1953
Noventa Vicentina	2045	2188	1912	2048
Fiesso Umbertino	1842	1820	1928	1863
Bovolino di Buttapietra	1932	2042	2054	2009
Belfiore d'Adige	1950	1875	1919	1915

Tab. 3 - Mean GDD of the each site during 2005-2007

Figures 5, 6, 7, 9, 10 and 11 show the GDD patterns in all the locations during the 3 years: Noventa Vicentina and Bovolino di Buttapietra had the smallest differences whilst Fiesso Umbertino and Castelfranco Veneto the highest.

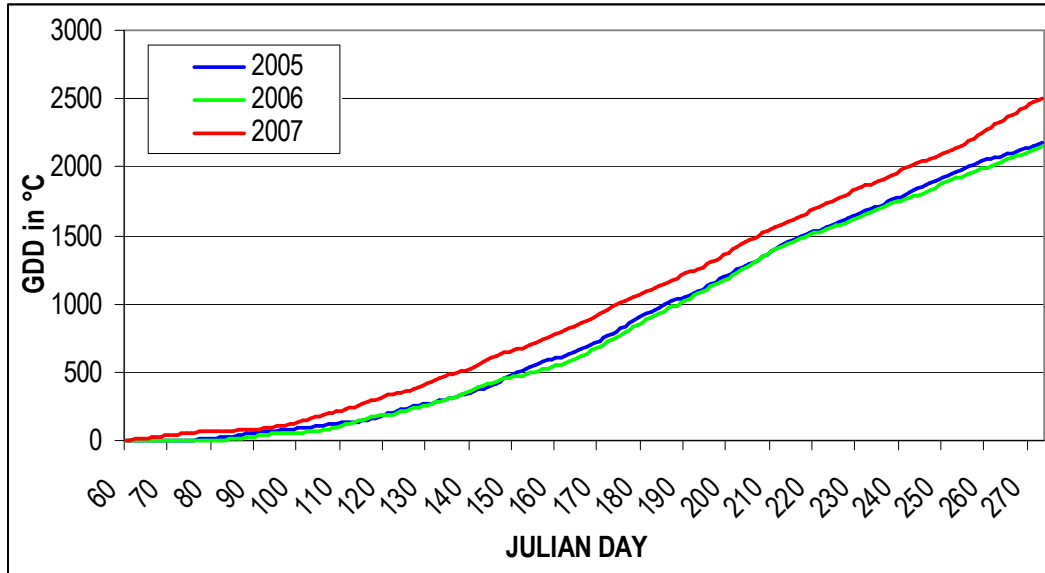


Fig. 5 - GDD (1st March- 30 September) of Legnaro during the period 2005-2007

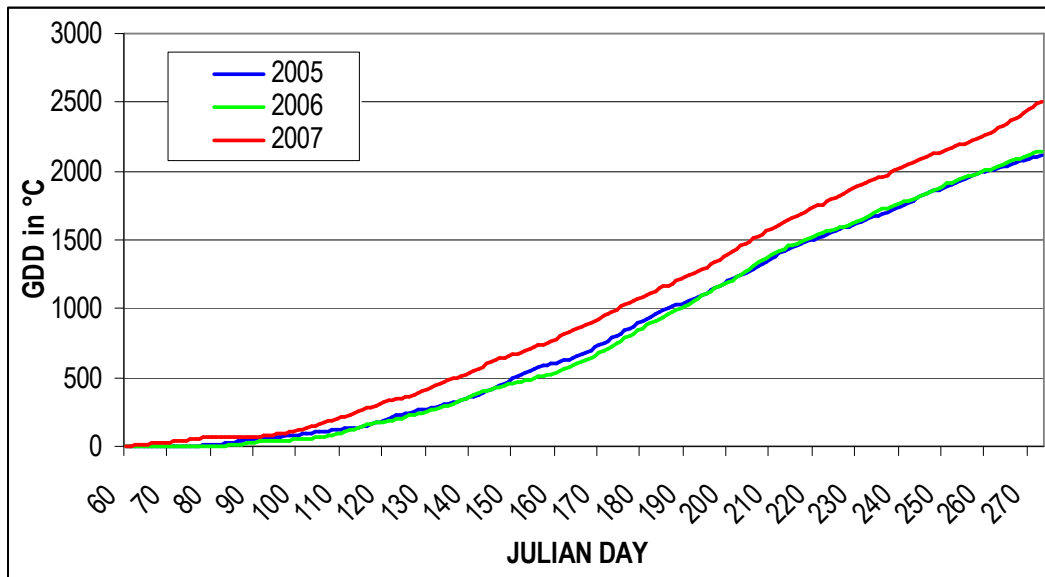


Fig. 6 - GDDs (1st March- 30 September) of Castelfranco Veneto during the period 2005-2007

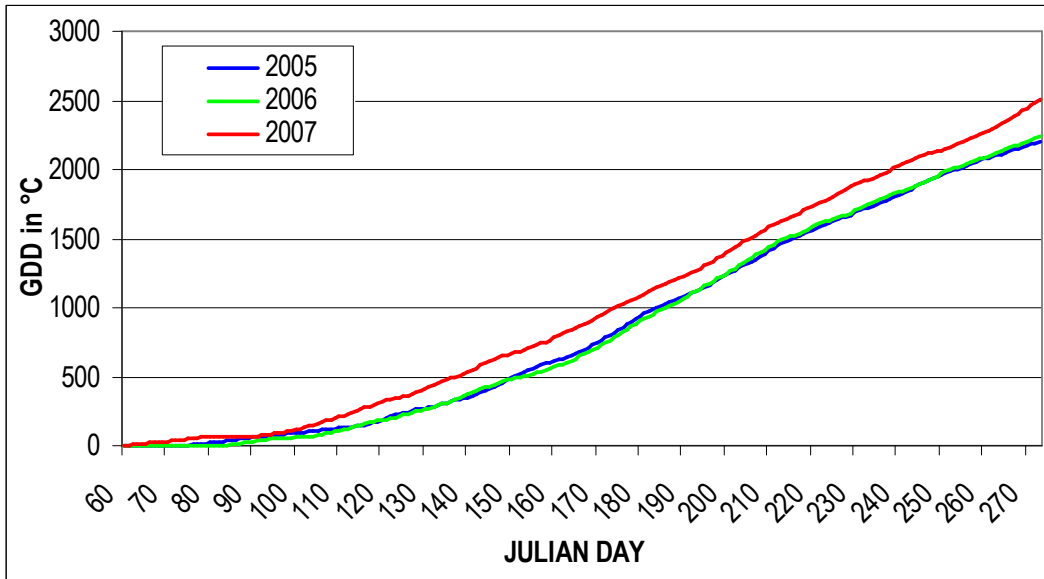


Fig. 7 - GDDs (1st March- 30 September) of Buttapietra during the period 2005-2007

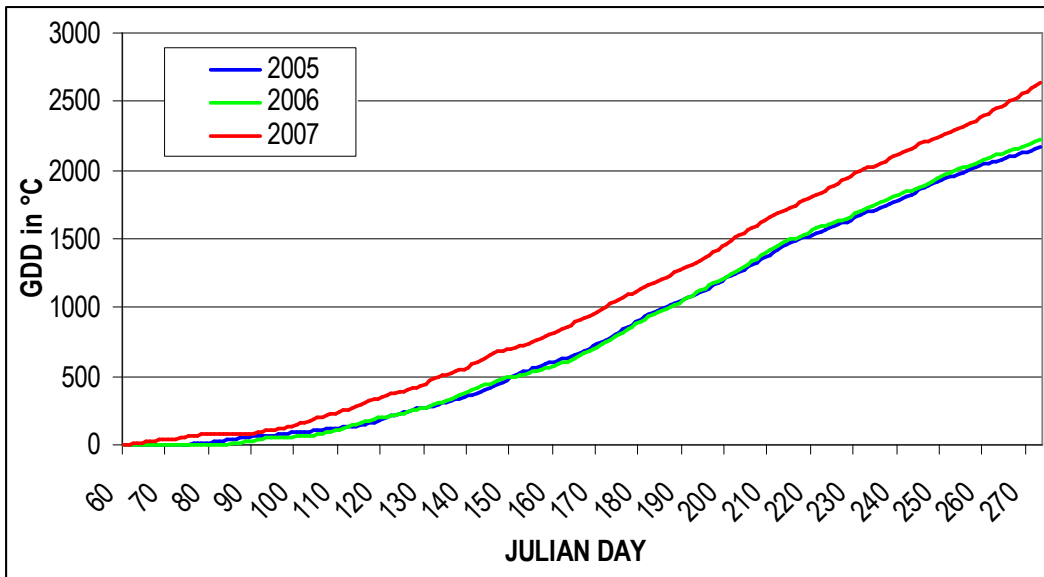


Fig. 8 - GDDs (1st March- 30 September) of Fiesso Umbertiano during the period 2005-2007

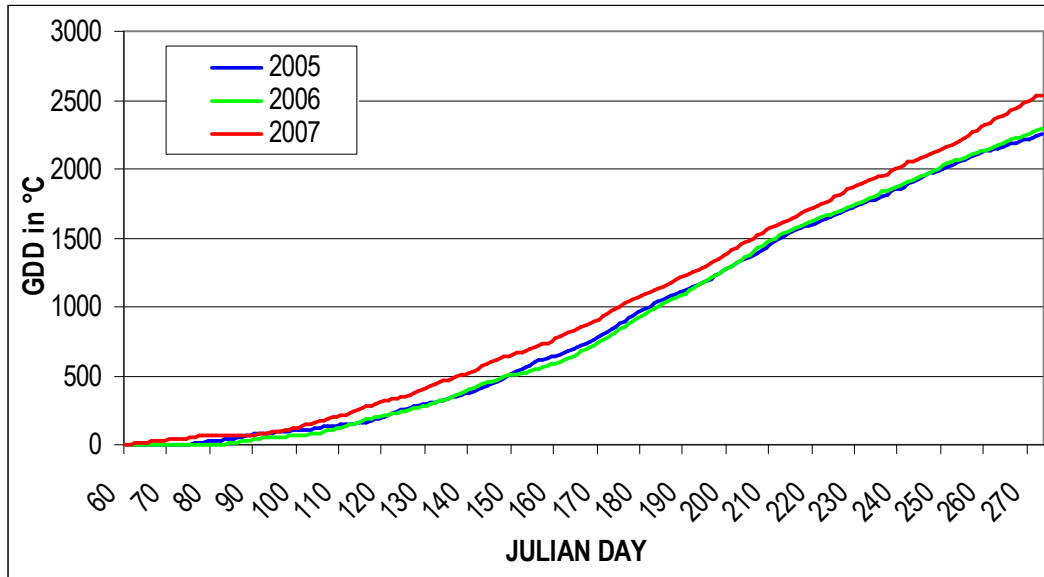


Fig. 9 - GDDs (1st March- 30 September) of Noventa Vicentina during the period 2005-2007

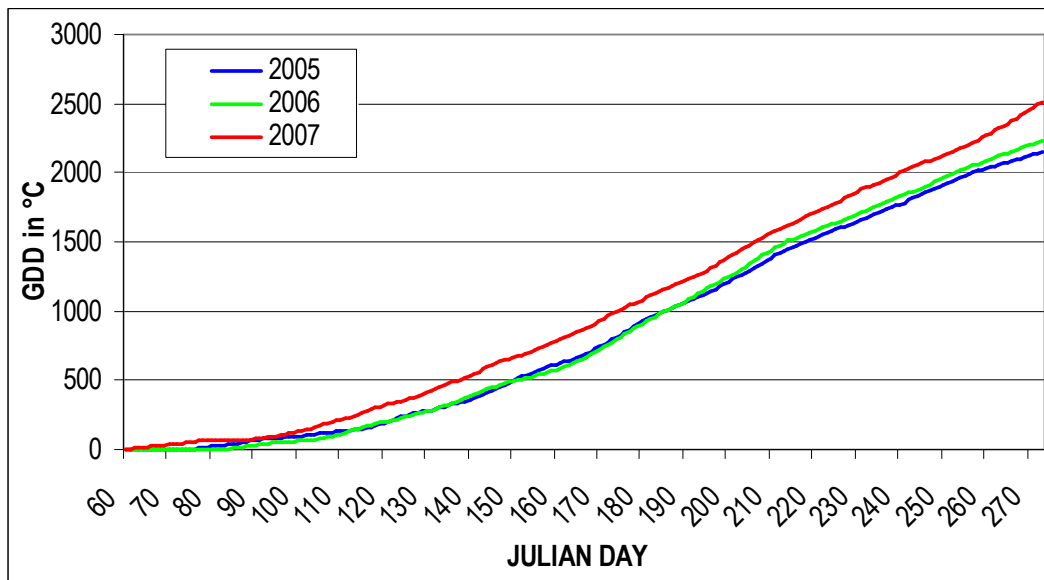


Fig. 10 - GDDs (1st March- 30 September) of Belfiore d'Adige during the period 2005-2007

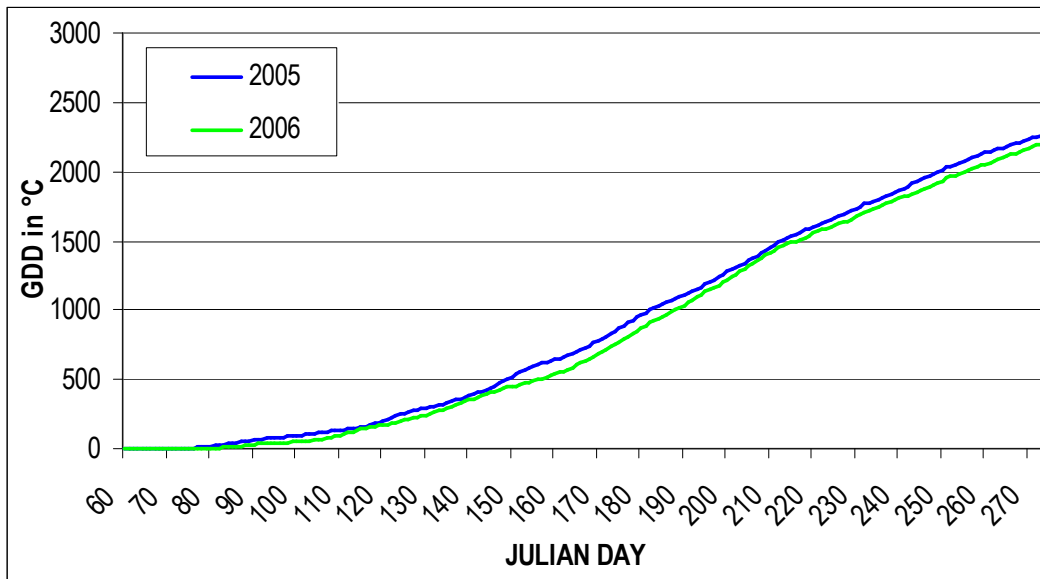


Fig. 11 GDDs (1st March- 30 September) of San Stino di Livenza during the period 2005-2006

The phenological response of maize to GDDs accumulation was affected by FAO class, hybrid and site (Tab. 3)

For this study, it was particularly interesting discriminating the behaviour of FAO classes 500 and 600 over all the sites and years because it might affect the development of leaf area index and the crop coefficient in the water balance.

In particular FAO classes, 500 and 600, have a different capacity in reaching the different phenological stages (Fig.12). As it expected, FAO 500 reaches them earlier than 600 one, even though they were close for number of the days from sowing to harvesting and for the growing degrees days at the same stage. Thus, hybrids of the same FAO class showed significant differences because of the genetic proprieties (Tab.4).

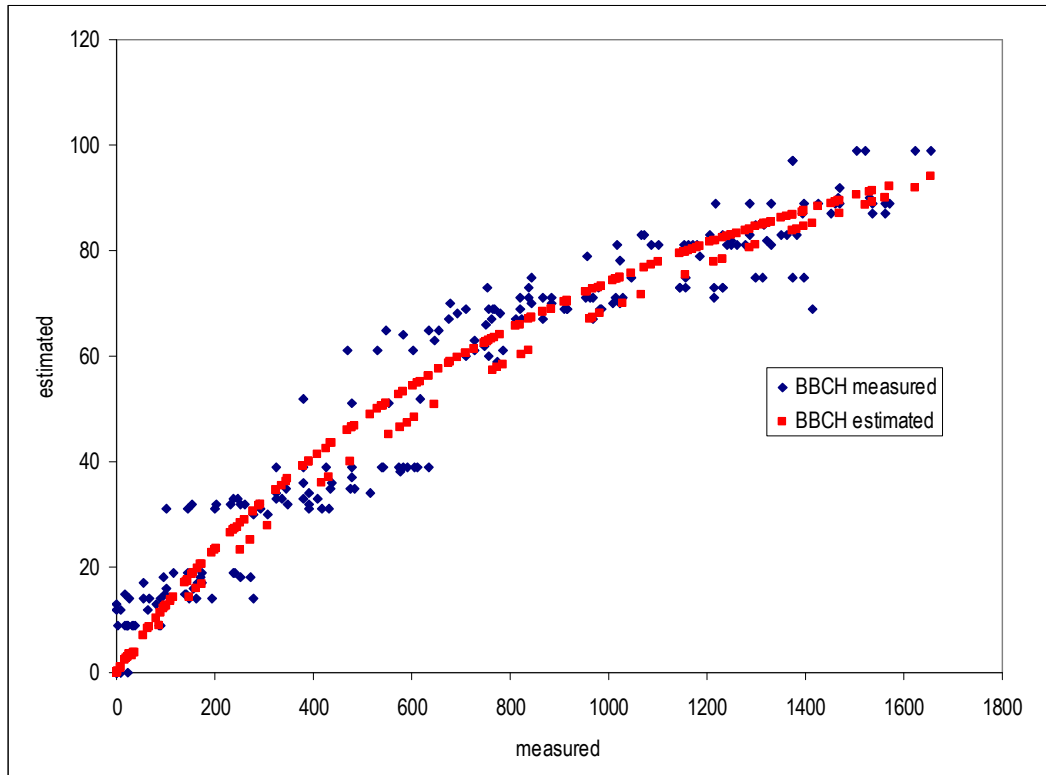


Fig. 12 – Dummy variables’ analysis: FAO class 500 and 600

	ESS (sum squares)	Degree of of freedom	RMS (root of mean squares)	F-value	Prob>F
FAO class	15633	225	152.93	2.09	0.00
Hybrid	17589	215	132.63	4.16	0.00
Site	23386	215	125.03	7.92	0.01

Tab. 4 - Statistical analysis among FAO classes, hybrids and sites

Differences among the locations were observed as well. This means that, even the effect of the years was the same in the 7 places, there is an effect due to some meteorological parameters closely connected local climate, especially the rainfall.

4. Conclusions

In this work the importance of having a regional phenological network was highlighted. Phenology is getting more important nowadays and its role is closely connected with the global and in this case local climate change.

In fact records, coming from this network, will be used for scientific research and not only, as in this case, for phenological study but they may help the research in the irrigation management (see Chapter 5) and in the future they can be related with the historical meteorological dataset to analyze crop maize the long term period.

In this way it is possible studying the influences of the climate change on plants on local scale and it is possible compare these trends with the trends of the other countries in Europe.

In particular the results show the significant difference of maize in Veneto region in the 7 sites that were used in this study. Different FAO classes, 500 and 600, and different hybrids of the same classes in 2005, 2006 and 2007 demonstrated difference in reaching the different development stage, observed with BBCH scale.

A strong difference is due to the meteorological trend of the year: 2007 it was really hotter than the other two years of the project, but other differences are due to the other factors (location and hybrids).

This can be used like a good management in the choosing of FAO classes and hybrids by the farmers, choosing the best one according to the sites and the local climate.

Nevertheless taking all the 500 and 600 classes only small differences of GDD necessary to reach a given phenological stage were found. This suggests that for the water balance simulator used in this study, it is not necessary an improvement on the phenological module able to recognize the effect of the different FAO class in affecting crop coefficient and water need.

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Link

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- <http://topshare.wur.nl/cost725/70902> on line 31.12.2007
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- www.fao.org on line 31.12.2007

Chapter 4

IRRIMANAGER: A SIMPLE SOIL WATER BALANCE MODEL FOR ENVIRONMENTAL APPLICATIONS IN THE VENETO REGION

1. Introduction

Crop is defined as an “Aggregation of individual plant species grown in a unit area for economic purpose”.

Growth is defined as an “Irreversible increase in size and volume and is the consequence of differentiation and distribution occurring in the plant”.

Simulation is defined as “Reproducing the essence of a system without reproducing the system itself”. In simulation the essential characteristics of the system are reproduced in a model, which is then studied in an abbreviated time scale.

A *model* is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Also, a model is “A representation of an object, system or idea in some form other than that of the entity itself”. Its purpose is usually to aid in explaining, understanding or improving performance of a system.

A model is, by definition “A simplified version of a part of reality, not a one to one copy”. This simplification makes models useful because it offers a comprehensive description of a problem situation. However, the simplification is, at the same time, the greatest drawback of the process. It is a difficult task to produce a comprehensible, operational representation of a part of reality, which grasps the essential elements and mechanisms of that real world system and even more demanding, when the complex systems encountered in environmental management (Murthy, 2004).

The Earth’s land resources are finite, whereas the number of people that the land must support continues to grow rapidly. This creates a major problem for agriculture. The production (productivity) must be increased to meet rapidly growing demands while natural resources must be protected. New agricultural research is needed to supply information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate around the world. In this direction explanation and prediction of growth of managed and natural ecosystems in response to climate and soil-related factors are increasingly important as objectives of science. Quantitative prediction of complex systems, however, depends on integrating information through levels of organization, and the principal approach for that is through the construction of statistical and simulation models. Simulation of system’s use and balance of carbon, beginning with the input of carbon from canopy assimilation forms the essential core of most simulations that deal with the growth of vegetation.

Systems are webs or cycles of interacting components. Change in one component of a system produces changes in other components because of the interactions. For example, a change in weather to warm and humid may lead to the more rapid development of a plant disease, a loss in yield of a crop, and consequent financial adversity for individual farmers and so for the people of a region. Most natural systems are complex. Many do not have boundaries. The bio-

system is comprised of a complex interaction among the soil, the atmosphere, and the plants that live in it. A chance alteration of one element may yield both desirable and undesirable consequences. Minimizing the undesirable, while reaching the desired end result is the principle aim of the agro meteorologist.

In any engineering work related to agricultural meteorology the use of mathematical modelling is essential. Of the different modelling techniques, mathematical modelling enables one to predict the behaviour of design while keeping the expense at a minimum. Agricultural systems are basically modified ecosystems. Managing these systems is very difficult. These systems are influenced by the weather both in length and breadth. So, these have to be managed through systems models which are possible only through classical engineering expertise.

There are some types of models and depending upon the purpose for which it is designed the models are described into different groups or types. Of them a few are :

a. *Statistical models*: These models express the relationship between yield or yield components and weather variables. In these models relationships are measured in a system using statistical techniques. Example: Step down regressions, correlation, etc.

b. *Mechanistic models*: These models explain not only the relationship between weather variables and yield, but also the mechanism of these models (explains the relationship of influencing dependent variables). These models are based on physical selection.

c. *Deterministic models*: These models estimate the exact value of the yield or dependent variable. These models also have defined coefficients.

d. *Stochastic models*: A probability element is attached to each output. For each set of inputs different outputs are given along with probabilities. These models define yield or state of dependent variable at a given rate (see chapter 2).

e. *Dynamic models*: Time is included as a variable. Both dependent and independent variables are having values which remain constant over a given period of time.

f. *Static*: Time is not included as a variables. Dependent and independent variables having values remain constant over a given period of time.

g. *Simulation models*: Computer models, in general, are a mathematical representation of a real world system. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil

conditions as well as crop management. These models use one or more sets of differential equations, and calculate both rate and state variables over time, normally from planting until harvest maturity or final harvest.

h. *Descriptive model*: A descriptive model defines the behaviour of a system in a simple manner. The model reflects little or none of the mechanisms that are the causes of phenomena. But, consists of one or more mathematical equations. An example of such an equation is the one derived from successively measured weights of a crop. The equation is helpful to determine quickly the weight of the crop where no observation was made.

i. *Explanatory model*: This consists of quantitative description of the mechanisms and processes that cause the behaviour of the system. To create this model, a system is analyzed and its processes and mechanisms are quantified separately. The model is built by integrating these descriptions for the entire system. It contains descriptions of distinct processes such as leaf area expansion, tiller production, etc. Crop growth is a consequence of these processes.

In these scenario of multi purpose models in agriculture, *Irrimanager* is a simulation model of water balance and it is also the pre-processor of *IrriWeb®*, the web face of the same service.

Irrimanager is created by Altavia s.r.l., Bologna, Italy, (Giannerini G., 1993) in 1999 and it was validated from CER (Canale Emiliano Romagnolo) in some crops of the Emilia Romagna Region.

Only in 2003 this service started to be used by Arpav, Agrometeorological Unit of Teolo, Padova (Italy). Arpav is the Environmental Agency for Veneto Region and in particular the agrometeorological unit is a special part of it, busy in the applications of agrometeorology to support the farmer management.

This chapter describes the structure of the simulator and its interface with the user.

2. Description of the IrriWeb®

2.1 The double face of IrriWeb® : web and mobile version

The decision of when and how much to irrigate is very important. Many times the first irrigation is started late, causing the crop to stress due to a lack of water. If irrigation is delayed until visible stress symptoms (such as plant wilting) appear, the crop has already suffered some amount of damage.

How long it lasts and when the stress occurs will determine how the crop's development is affected and whether the result will be a lower yield and/or poor quality, which reduces the profit potential for the producer.

IrriWeb® is an on-line decision support system for use in planning and scheduling irrigation operations. The system downloads weather data from local weather stations and uses those data, in combination with farm-specific information about fields, crops, and actual irrigation practices provided by irrigators, to estimate soil moisture conditions and to forecast irrigation schedules.

This irrigation scheduling computer program is a very good tool for determining when and how crops' moisture stress can be avoided or at least reduced.

This model was developed to predict evapotranspiration and soil moisture changes, which could be used either for scheduling irrigation or crop water-use studies. The general form of the model is reported here , and its validation for maize is described in the subsequent chapter. The program is designed to require a limited amount of readily available data and to be straightforward and easy to use. A regional location for the farm, the type of crops planted, emergence dates for the crops and irrigation records will have to be entered for each field. This should be done at or soon after planting; information can be changed later if needed.

The farmer can use this service as unregistered user just to have a daily advice or can get a user name and password to check during the irrigation season the advice in the crops that are previously registered. Recording of the data begins on the date selected for estimating the beginning soil moisture conditions and continues until the crop is near to maturity. An allowable deficit is set for each crop, and it is used to determine when the crop has reached the point that it needs to be irrigated. Once the data are entered, the scheduling program can predict when irrigation is needed over the next 24 hours.

The irrigation scheduling program is used by many Veneto farmers for maize and grapevine that are the main crops in this region but the model supports the major agricultural crops in Italy.

Drainage, soil type and rainfall should be considered for individual fields. When these conditions are combined with the farmers' judgment, the irrigation scheduling program can be a valuable asset in coordinating labour and water resources to satisfy crop water needs.

First-time users of the program usually think it is causing them to water too early and maybe too often. In most cases, by the end of the season, they see the benefit of improved yields by following the programs recommendations on when to irrigate. The computer service is available from the Internet at no charge by going to <http://irrigation.altavia.eu/LoginARPAV.aspx> (Fig. 1)

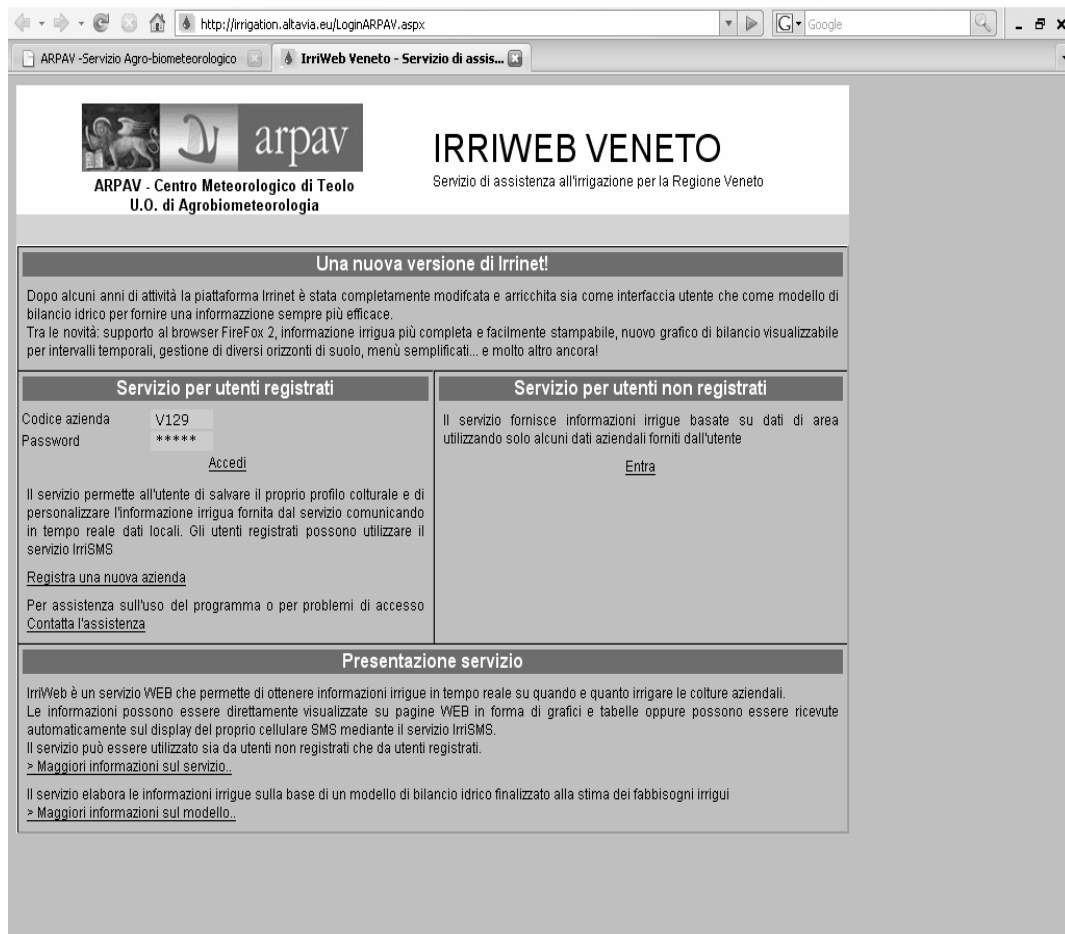


Fig. 1 - IrriWeb®'s quick start page on line

2.2 Requirements of computer package for farmer use

A model designed to be operated by farmers and growers, at a reasonable cost, must be constrained by the availability of site - specific information. In general the only data available regarding the site are: location; crop type, variety and age (for orchards and grapevine); planting date; irrigation equipment available; and soil textural class (topsoil and subsoil).

In fact IrriWeb® is in this way and it requires data on the field level.

These data are provided by the user and entered into the underlying daTab.ase by means of forms in a number of dedicated web box in starting page. This page is intended as an easy way for farmers to get started in using the IrriWeb® , and the majority of data required are selected from a list. More than one crop can be registered on line for the scheduling.

Field data required are:

Location: clicking on the Veneto map the user can choose the position of the crops but it is also possible put the Gauss Boaga X and Y.

Crop: selection of the crop choosing by the list that is for 22 crops (herbaceous and arboreous) (Fig. 2)



Fig. 2 - Selection of location from Veneto map

Details of crop: date of seeding or vegetative regrowing, harvesting date, distances on and between rows, year of the beginning of the system (only for arboreus crops) (Fig.3)

The screenshot shows a web browser window with the URL `http://irrigation.altavia.eu/Registered/ComColturaStep2.aspx?Ucod=`. The page header includes the ARPAV logo and the text 'IRRIWEB VENETO Servizio di assistenza all'irrigazione per la Regione Veneto'. Below the header is a navigation menu with links for 'Menù principale > Gestione colture', 'Richiedi assistenza', and 'X Esci dal servizio'. The main content area is titled 'Registrazione nuova coltura -' and contains two form sections:

Tipologia culturale

COLTURA: Scegliere una coltura... (dropdown menu)

DESCRIZIONE: (text input field)

Il menù a tendina contiene la lista delle tipologie di coltura irrigua gestite dal sistema
Campo facoltativo: serve per differenziare appezzamenti diversi della stessa coltura

Dettaglio colture arboree

SESTO DI IMPIANTO: Distanza sulla fila m (input field), Distanza tra le file m (input field), Pianta per Ettaro risultanti (input field)

CONDUZIONE INTERFILARE: Inerbito (dropdown menu)

DATA DI RACCOLTA: (input field)

VIGORE PORTINNESTO: Vigore Medio (dropdown menu)

ANNO DI IMPIANTO: 2007 (dropdown menu)

FORMA DI ALLEVAMENTO: Qualunque (dropdown menu)

Le informazioni sul sesto di impianto sono obbligatorie per le colture di tipo arboreo

Fig. 3 - Crops details: General crop detail in the first box and only for arboreous agronomic detail in the second one

Meteorological data: selection of a meteorological station from the list, choosing the closest one to the field. If the farmer has got an owner rain gauge, the values can be added (Fig. 4)

Soil : slope and texture of the field. If the texture is unknown the program will take the soil data automatically by the ARPAV soil map of Veneto region (Fig.4)

http://irrigation.altavia.eu/Registered/ComCulturaStep2.aspx?Ucod=

ARPAV - Servizio Agro-biometeorologico IrriWeb Veneto - Servizio di assis...

Dati climatici

STAZIONE METEOROLOGICA:

BATTERIA FALDA:

PLUVIOMETRO AZIENDALE:

La stazione meteo viene assegnata in base alla localizzazione sulla mappa operata nella pagina precedente, può essere modificata manualmente scegliendo dal menù a tendina.

La batteria di falda viene assegnata in base alla localizzazione sulla mappa operata nella pagina precedente, può essere modificata manualmente scegliendo dal menù a tendina. Se compare "nessuna batteria di falda" significa che non ci sono batterie di falda presenti nell'area; in questo caso gli eventuali dati di profondità falda possono essere registrati dall'utente andando in menù principale > dati falda.

Per definire un nuovo pluviometro aziendale ritornare al menù principale. Per ogni pluviometro possono essere registrati durante la stagione dati di pioggia in alternativa a quelli forniti dalla stazione meteo

Dati terreno

PENDENZA:

ORIZZONTI e GRANULOMETRIA

Ordine	Spessore metri	Sabbia %	Argilla %	Scheletro %
1	0,5	17	23	0 Modifica

Nuovo orizzonte >

Ordine 1 Spessore metri

DA GRANULOMETRIA % Argilla %


Scheletro

[Aggiorna dati](#) [Annulla modifiche](#)

Possono essere inseriti uno (obbligatorio) o più orizzonti di suolo ciascuno con la propria granulometria. Inserire i valori di sabbia e argilla (opzione "da granulometria") oppure scegliere una classe tessiturale standard. Nel caso di unico orizzonte usare lo spessore standard di 1,4 metri

Fig. 4 - Meteorological and soil input

Irrigation management: kind of irrigation system choosing by the list, distance on and between rows and nominal flow rate (l/h) (Fig. 5). The irrigation amount can also be added if this data are available to get meaningful results from the model. In fact in this case all of the irrigation advice will be calculated considering the real water deficit in to the soil. If information of the irrigation amount is not provided, the model will simulate an increasing water stress in the soil and will continue the advice irrigation.



Impianto irriguo

TIPO IMPIANTO IRRIGAZIONE

CARATTERISTICHE IMPIANTO MICROIRRIGUO

Scorrimento ▼

Distanza erogatori sulla fila m

Distanza erogatori tra le file m

Portata singolo macchinatore l/h

Questi valori sono obbligatori nel caso di microirrigazione

Fig. 5 - Irrigation System input: if it is a drip system more details are required

2.3 Output of IrriWeb®

The output are clear and simple to interpret. They indicate when the next irrigation is due and how much water has to be applied. The default output should only contain that information needed to schedule the irrigation. However, full details of simulated water balance should be available in case there is a query on the advice. One criticism of bureau services is that generally it is not possible to see how the advice was derived and whether there had been any errors or inappropriate assumptions in the model uses (T. Hess, 1996).

Irrigation advice and explanation are provided in tables and graphics on line but also with the possibility of setting up an sms service to deliver the results.

Farmers interact with IrriWeb® by a web browser, navigating in a collection of pages by means of traditional web page menu. The main web page for the user's evaluation of *actual evapotranspiration* and the data of the estimated irrigation needs is shown in Fig. .The page provides information concerning all of the farmers' fields. Each field is identified by a short description of crop, meteorological station and irrigation data. The estimated amount of available soil water is presented graphically and numerically as soil moisture. In this way the user can check in the graph the soil moisture's trend (red line) but also maximum and minimum thresholds (green and black line), rainfall (blue columns) and irrigations of the farmer (orange columns) are lighted (Fig. 6). The values of soil moisture have to be between the two threshold lines. The minimum line represents the values under which the plant can be stressed and the maximum represents the values after which there is water's loss in the soil.

There is also a *IRRISMS* service (*sms* means short messaging service) in which a text is sent by the server to user's mobile phone, so the farmer can know immediately the irrigation's needs without checking on line. Irrisms is easy to understand and it informs about the date of irrigation and for how long (it depends on the irrigation flow rate, previously input during the registration step). The user can get this service for free and it is available for 3 crops at maximum.

IrriWeb® is always available on line during the year but the text's service is working only during the irrigation season.

Mobile phones based dissemination systems of services are used in both interactive and non interactive mode. The most advantageous feature of mobile phone based systems is that farmers are able to communicate with the web-based systems, while in the field and can request for advice concerning a newly discovered problem.

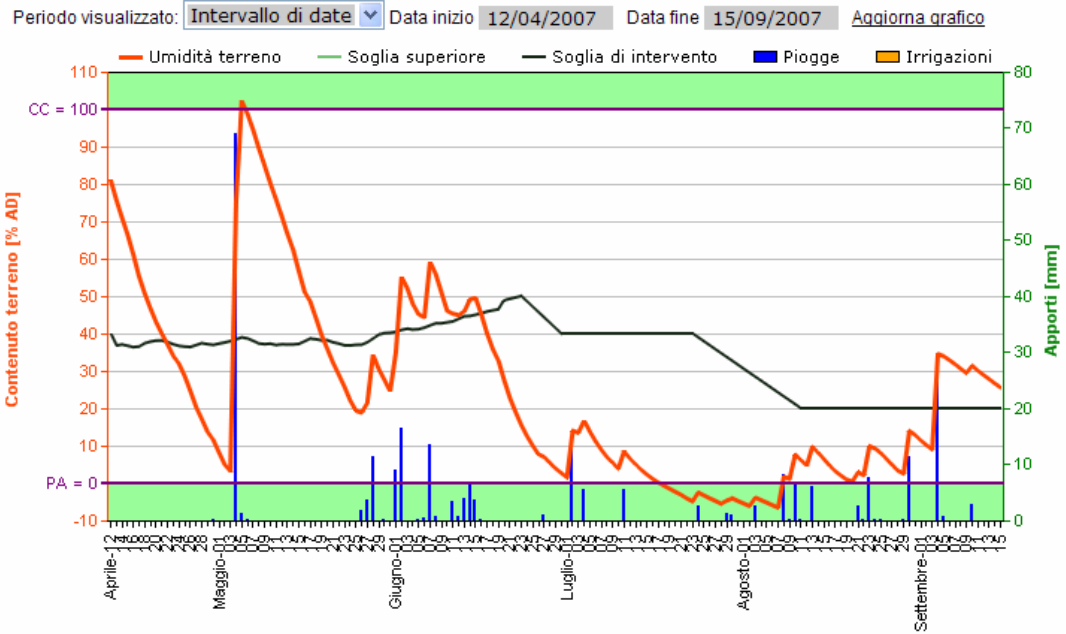


Fig. 6 Public output on the web page

2.4 User acceptance

In Veneto Region there are 43995 irrigated farms with a surface between 1 and 100 ha.

IrriWeb® was used actively by 300 farmers in 2007, with more than 1100 contacts and 3700 sent txt on the mobile phone .

Here the main crops registered are corn and grapevine. The number of users is continually increasing, year after year. Right now, Irrimanager is used by 8 regions in Italy in total and it is studied for scientific validation and implementation by 2 of these regions (Veneto and Emilia Romagna).

3. Description of Irrimanager: an easy water balance model processor

Irrimanager is the name of IrriWeb® 's pre processor program. The model is for the irrigation's scheduling but it is available also for the analysis of water balance in the soil-plant-atmosphere system.

It is available only on an Altavia's server and it requires a special user and password because it is not a service for the clients but it is the working-face of the software. It can be used by public research that are busy in its validation and implementation.

The model was born either for herbaceous crops both for harbours ones, one part of this model is common to the two cases but very often two different sub-model are defined. The first part of the model, called "Pre-Processor", is completely separated from the model: it means that it is just the condition of the "surrounding".

The model estimates supplementary irrigation water requirements to maintain optimal conditions for plant growth: for that it maintains a soil moisture level between maximum threshold (close to the field capacity) and minimum threshold (close to the permanent wilting point). If the lower threshold is being reached, supplementary irrigation water is added. How much and how long depends on irrigation system.

Speaking in a scientific way about the question of the relationship between water and agricultural activities, it is necessary using modelling techniques (Marletto, 2001). In hydrological studies and in the programming and managing of the water resources it is very used the water balance equation. This water balance equation is based on the estimation of the variations of water source, measuring and of course evaluating the differences between input and output.

Water balance is expressed by this formula

$$\boxed{ETE = P + F + I + \Delta\theta - Pr - R}$$

where

- **ETE** = effective evapotranspiration i.e. the real water losses trough atmosphere with the evaporation
- **P** = precipitation

- **F** = contribution of waterground Table
- **I** = Irrigation
- **$\Delta\theta$** = variation of soil moisture
- **Pr** = drainage
- **R** = runoff

About evapotranspiration note that:

Reference crop evapotranspiration (ET_0) is computed from meteorological data and so the FAO Penman-Monteith method is used in the model. Every day ARPAV sent meteorological file with these values to Altavia's server to put the data in the server and to obtain the irrigation advice

Maximum (or Crop) evapotranspiration model (ET_m) is calculated, according by multiplying the reference crop evapotranspiration, ET_0 , by a crop coefficient, K_c :

$$ET_c = K_p ET_0$$

where

ET_c crop evapotranspiration [mm d-1]

K_p pan coefficient [dimensionless]

ET_0 reference crop evapotranspiration [mm d

K_p , pan coefficient, is calculated with Doorenbos and Pruitt (1977)

The structure of Irrimanager is outlined in Fig. 6 an 7, where a chart of soil and crop's model is graphed.

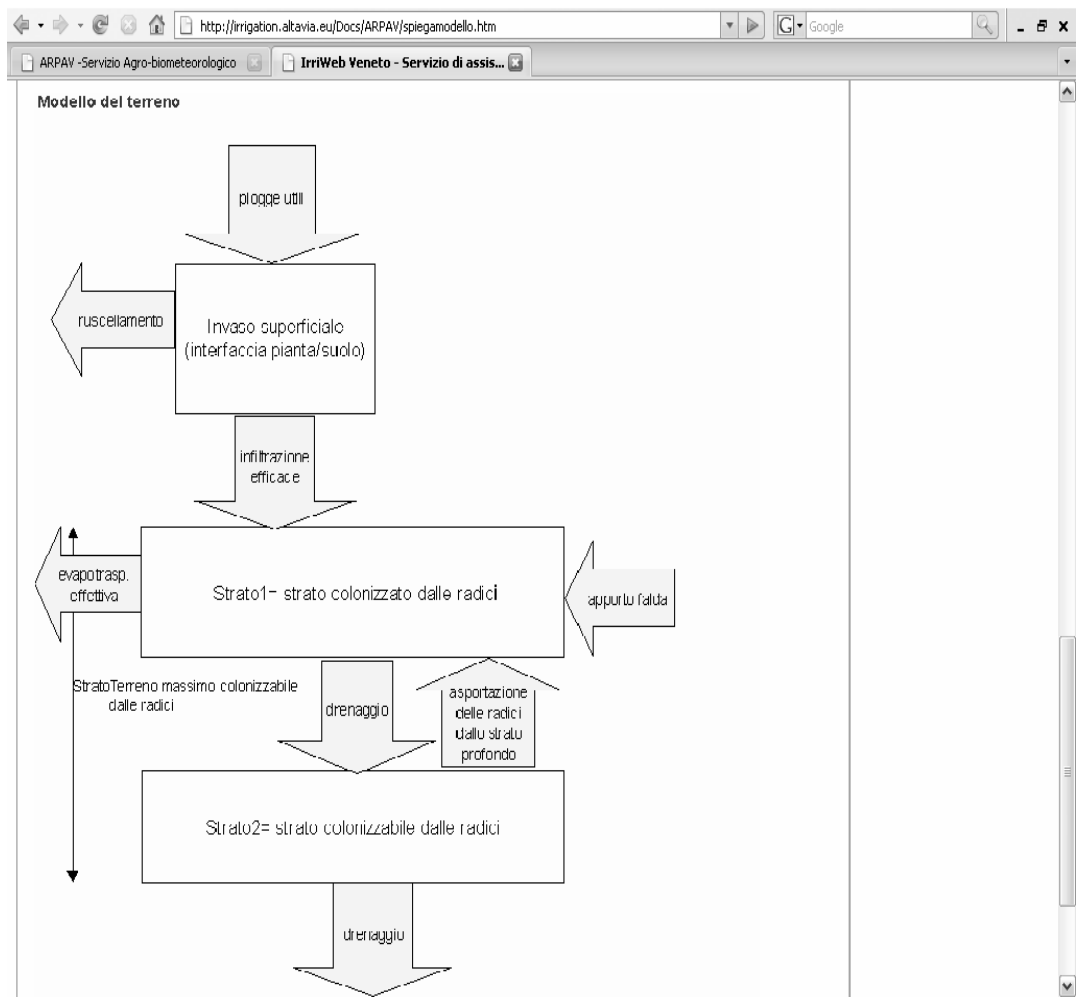


Fig. 6 – Flow chart of soil's model

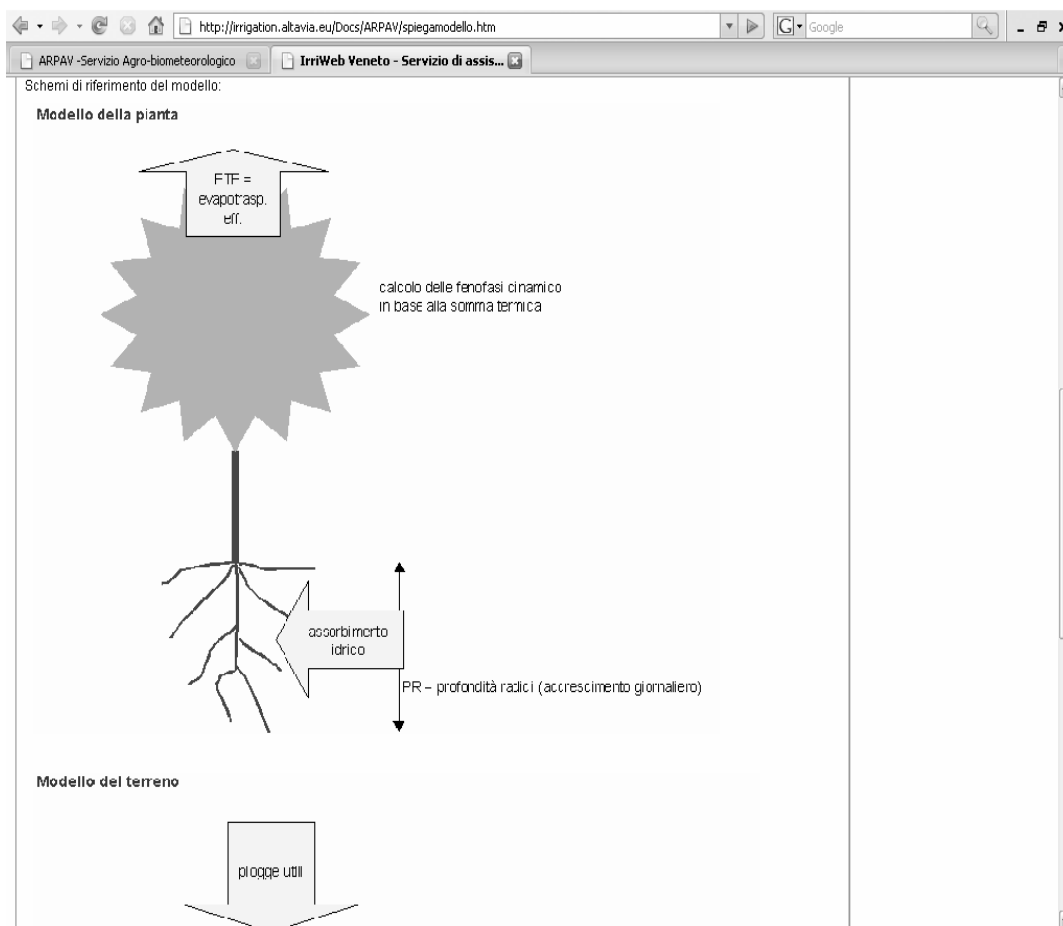


Fig. 7 – Flow chart of plant's model

There are 6 six main simulated proceedings in the model:

- 1- Root's growing with a function that estimates the effect of temperature, soil moisture under the roots and phenological stages based on a maximum rate that is typical for each crop. This simulation was estimated starting from the experimental samples of CER on Emilia Romagna's crops and soils.
- 2- Phenological stages of each crop, calculated on GDD (Growing Degree Days) on zero basis.
- 3- Irrigation needs with evapotranspiration from meteorological records and crop coefficient Kc values found were used to estimate Kc according to the method

proposed by Doorenbos and Pruitt (1986) for the initial, mid and late crop growth seasons.

4- Estimation of decreasing of soil's moisture using up on crops' stress For each crop there is a value of threshold under which there is a reduction of water use following Doorenbos and Pruitt methodology but modified on CER's experimental records.

5- Estimation of groundwater table contribution to crop ET.

6- The dynamic of the water trough the soil with a cascade model or tipping bucket model. It considers 3 different buckets on the soil: the first one made by surface soil- atmosphere; the second one considering the effective rooting depth at the moment of the simulation and the lat one that can be explored by the roots' growth. In this way, the water going out from the bucket is calculated and it is the water's quantity that exceeds the field capacity of the layer's bucket; it is calculated by Driessen (1991). Two kinds of water losses : superficial one (runoff) from the first layer (soil-atmosphere) and a drainage from the second layer. It also calculates the water absorbed from the deeper layer taking to account the effective root growing. The soil hydrological characteristic are derived by the empirical pedotransfer using soil texture data.

3.1 Simulator's input

More than one crop can be input for the irrigation scheduling. It is also available the possibility to create a scenario with more than one crop when they are irrigated with the same system in order o optimize the irrigation management. This is important because the user can manage a general scenario with only one simulation and a only general irrigation advice will be given by the model (Fig. 8)

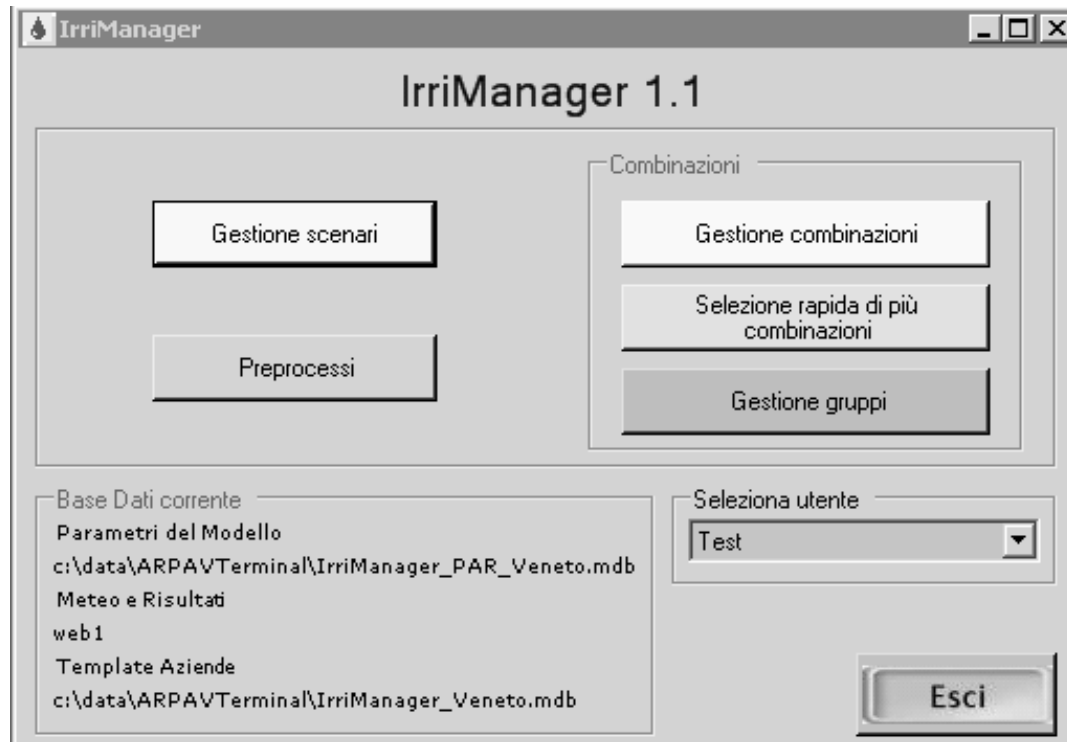


Fig. 8 - Quick start page of the simulator

In this thesis only one scenario with a single crop of maize was simulated.

Step one

Crop: choosing the crops by a list. The crops are the same of on line service but here it's possible to add other ones for scientific simulation. They will not available on line service anyway.

Sowing date: date of sowing or of vegetative re- growing if the crop is not herbaceous (Fig. 9)

Fig. 9 - Crop details and sowing date. If the crop is herbaceous more details are required

Step two

Soil texture: total depth of the studied soil; slope of the field; % of sand, clay and organic matter of the total horizon or the values' input of the single layers of the soil if they are known. The program will be calculate the right hydrological constants form USDA values that are previously registered on the equation model (Fig.10 a and 10 b)

Spess	Sabbia	Argilla	Schele	CIMUn	CCUn	PAUn	PSA	CIM	CC	PA	AD	Uz	Z	SumCl	SumC	SumP

Fig. 10 - a Soil input: slope of the filed and the horizons

IrriManager - Gestione Orizzonte

NUOVO ORIZZONTE

spessore dell'orizzonte [mm]

sabbia [%]

argilla [%]

scheletro [%]

Trova classe USDA -->

Imposta autom. S e A

Classe USDA

Sabbioso

<-- Seleziona

grandezze idrologiche derivate

PAunitario PA

CCunitario CC

CIMunitario CIM

PSA

AD

Calcola grandezze idrologiche

Salva

Chiudi

Fig 10b - Details required for each horizon

Step three

Meteorological station: name of the meteorological station and the year. In this case in Legnaro meteorological dataset starts from 1992 until nowadays, the other meteorological stations start from 2003. The meteorological files are added manually and previously made by ARPAV. A file is made in excel format and in an easy way. Two sheets are necessary, in the first one daily records of minimum, maximum and mean temperature and evapotranspiration are recorded, and in the second one hourly data of rainfall. In fact without hourly data the model can not work. In Legnaro, as a lot of other stations in the Veneto region, hourly rainfall data start in 1992, so it the reason of the adding only starting from this date.

Groundwater Table: the depth of water Table. There are three possibilities: 1)no water Table; 2) values from the instruments where present in the meteorological station; 3)steady ground water Table depth for all the cycle, input by the user (Fig. 11). If the ground

Scenario: NUOVO SCENARIO

Meteo

meteo

anno meteo

stazione Legnaro

anno 2007

falda

assente letta dalla batteria

valore costante [mm]: 2000

<< >>

Valida i valori

Annulla

Fig. 11 - Meteorological and ground water Table input

water Table is not present, the model will assume a constant depth about 3 m. Anyway this default value can be changed in the last section before seeing the simulation's results (Tab. 1)

Step four

Irrigation system: choosing from a list the kind of irrigation system. It is very important because the irrigation advice will change especially if there is a simulation with micro-irrigation system (Fig. 12)

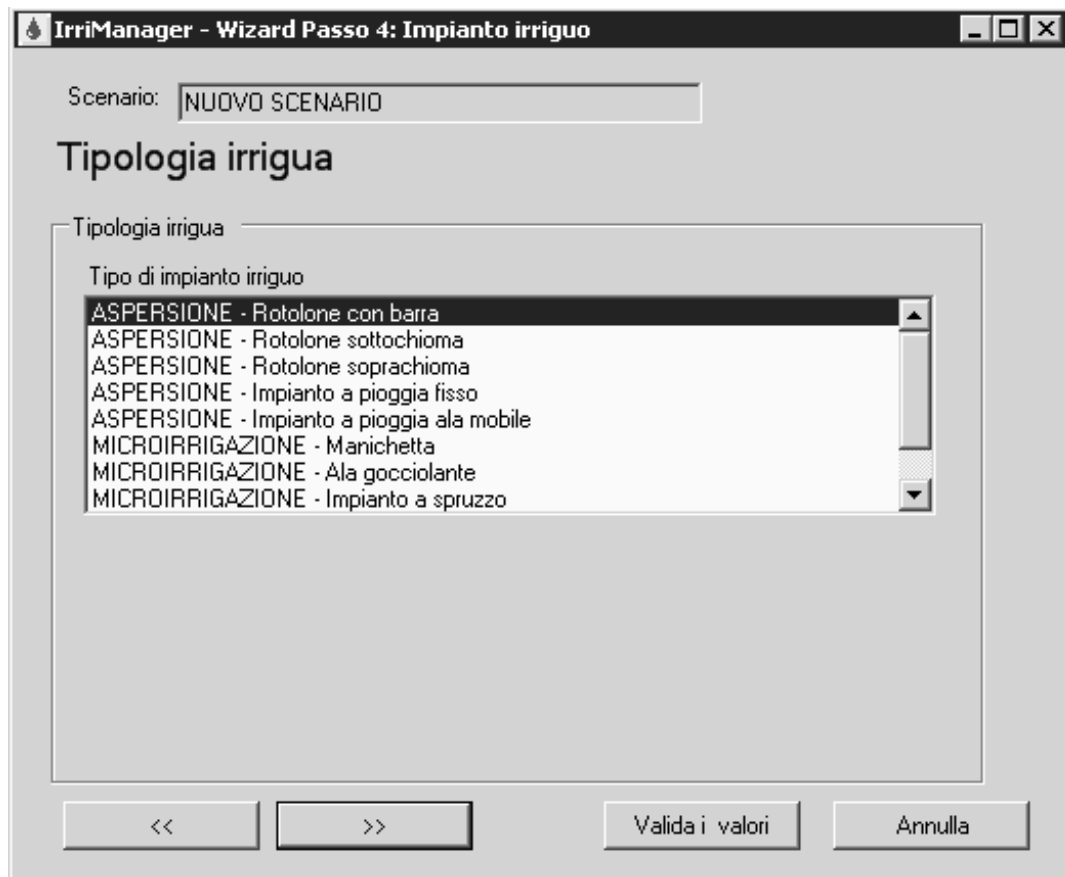


Fig. 12 - Details about irrigation system. If the system is micro more details are required

Step five

Water balance model: some important parameters have to be choose in the calculations' water balance like: the date of end (January 31 by default), the kind of irrigation advice (1) *no irrigation* advice: water balance simulates soil moisture without providing irrigation advice; 2) irrigation advice after the establishment of the crop; 3) irrigation during all crop cycle) and minor additional information about irrigation management (Fig.13)

IrriManager - Wizard Passo 7: Run del modello

Calcolo

Scenario:

Esegui modello e salva i risultati

Esegui modello e visualizza risultati

Parametri di calcolo

Bilancio irrigaz. autom.

data fine bilancio: Giorno Mese

parametri extra-bilancio

data richiesta data ultima irrigazione (fac.)

giorni previsione data iniziale pluviometro

turno massimo

Valida i valori Salva i parametri di calcolo Annulla

Fig. 13 - Kind and date of end of water balance

Step six

General parameters: in this section the values of some main parameters can be changed for specific situations Fig. 14, however the main ones are shown in Tab.1

The screenshot shows a software window titled "FIM_5_GENEPARS" with a "Scenario:" field set to "NUOVO SCENARIO". The main area is titled "Parametri generali" and contains a table with the following data:

Nome	Valore	Unimisura	Descrizione
DzTotStrati	1400	mm	Profondità dello strato di terreno preso in co
ProfoFaldaConvenz	3000	mm	Profondità di falda convenzionale utilizzata q
iProfoFaldaMinAcc	300	mm	Profondità di falda minima accettabile per i c
iProfoFaldaMaxAcc	3000	mm	Profondità di falda massima accettabile per i
fCoeffConversione	10	ad.	Coefficiente di conversione tra le profondità
KETAp	0.15	ad.	ETAp come frazione dell'ET0
PRMin	150	mm	profondità minima dello strato radicabile
KcTerraNuda	0.4	ad.?	coefficiente colturale della terra nuda
dzRipreVegeArbo	500	mm	profondità dello strato superiore radicato alla
UzParArbo	0.15	ad.	UzPar per le arboree
VAConvenzionaleA	1000	mm	Volume irriguo convenzionale fornito alla dat
ProAvvalni	20	cm	valore di ProAvva al primo gennaio
ProAvvaCalo	0.02	ad.	fattore di calo della profondità degli avvallam
ProAvvaStd	1	cm	valore standard di ProAvva
REIni	0	mm	RE iniziale al primo gennaio
SigmaLavo	0.61086	rad	angolo di lavorazione in radianti [0,61086 rad
KIPot	1	ad.	Coefficiente per il calcolo dell'infiltrazione p

On the right side of the table, there are input fields for "Nome parametro", "Valore parametro", "Unità di misura", and "Descrizione". Below the table, there are navigation buttons: "<<" and ">>" at the bottom center, ">> Seleziona" and "<< Salva modifica del parametro" on the right, and "Annulla" at the bottom right.

Fig. 14 - Box of the general input than can be modified according to the single needed

<i>Name of the input</i>	<i>Default values</i>	<i>Unit</i>
Depth considerate by the model	1400	mm
Max ground water Tab.le's depth	3000	mm
Min ground water Tab.le's depth	300	mm
Default ground water Tab.le's depth (When the data is not input)	3000	mm
Conversion Coefficient	10	ad
Min rooth depht	150	mm
Crop coefficient (wihtout crop)	0.4	ad?

Tab. 1 - Main input than can be modified in the model

Step seven

Saving file: the file with the input has to be nominated and then it can be saved in a *.xlm or *.csv format. This file will be used for the simulation.(Fig. 15)



Fig. 15 - Box for the saving input file

All the inputs are reported in Tab.2

<i>Name of inputs</i>	<i>Unit</i>
Crop	/
Data of sowing	dd/mm/yyyy
Slope of the field	%
Soil texture (sand and loam for each horizon considered)	%
Meteorological data (<i>daily</i> t max, min, mean and Et0 and <i>hourly</i> rainfall)	<ul style="list-style-type: none"> • Temperature in °C • Rainfall in mm/hour • ET0 in mm/day
Groundwater Table	mm
Irrigation system	
Water balance model (no irrigation, with irrigation system used)	/
Ending date of water balance	dd/mm/yyyy

Tab. 2 - Main input of Irrimanager

3.2 Data outputs

For the purpose of this study the main output are:

Phenological stages: Main phenological stages are calculated starting from 1 to 9 according to the BBCH. They are calculated with growing degrees days

Mean temperature and cumulate temperature: (or GDD, growing degrees days): they are the values of meteorological station and the calculated values of the sum temperature starting from the beginning of the year on 0 basis.

Deficit: it is the difference between the field capacity and the soil moisture trough the total horizon.

Soil moisture: It is the simulated value of the soil moisture in mm; the value on 1st January is the same value of the water field capacity.

Depth's root zone: it is the horizon in mm in which the roots grow during the phenological stages until a maximum depth is reached (mm)

Maximum Holding capacity, Field capacity and Permanent wilting point: values of this parameters are calculate with pedotransfer from the USDA Tab.les

Minimum and maximum soil moisture's thresholds the values between the soil moisture has to be maintained and the difference between these two values is the irrigation needs

Irrigation needs: the values of the irrigation in mm. It is the same advice that the on line service shows. It is calculated by the difference between the two threshold.

Each of these output can be showed also in a graphically way after saving the simulation's result. An example of the simulated depletion during all the year is shown in Fig 16.

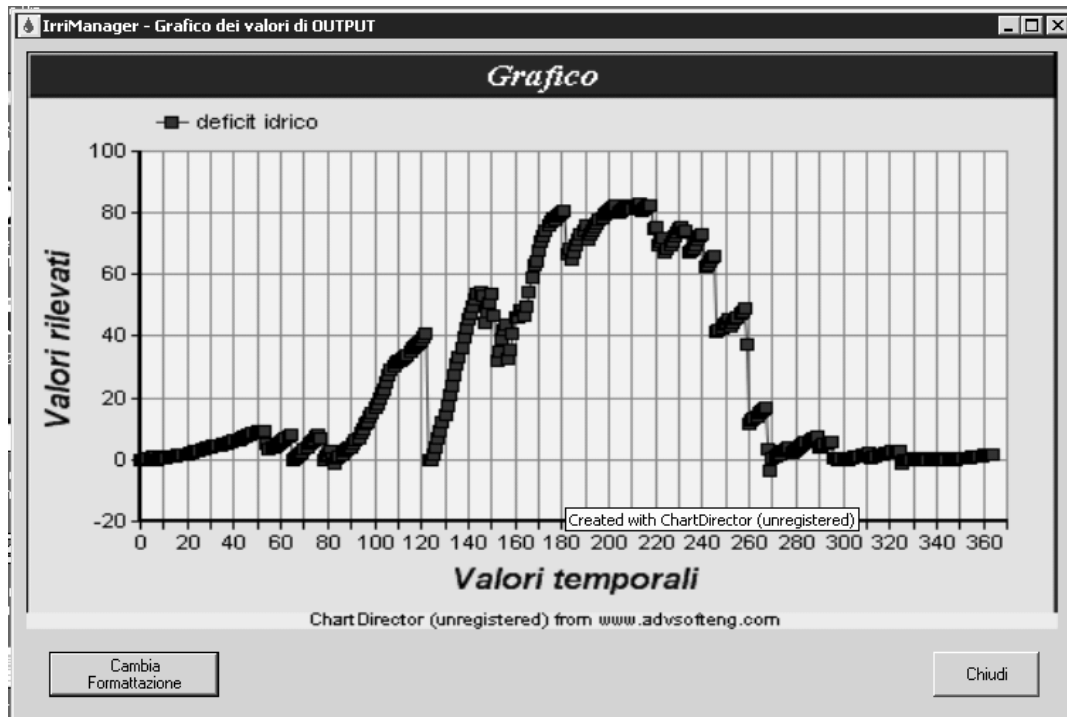


Fig. 16 - Example of simulated depletion's graph during all the year

All output are shown in Table 3

<i>Name of output</i>	<i>Unit</i>
GDD accumulation	°C
Phenological stage	BBCH
Depletion	mm
Soil moisture	mm
Maximum water capacity	mm
Field capacity	mm
Wilting point	mm
Maximum and Minimum threshold	mm
ET _a Actual evapotranspiration	mm/d
ET ₀ Reference evapotranspiration	mm/d
ET _m Maximum evapotranspiration	mm/d
Drainage	mm/d
Root grow depth	mm/d
Irrigation needed	mm/d
K _{c Crop}	

3.3 Version 1.1 and 1.2

IrriWeb® project has more than 15 years of Italian experience on the irrigation management with telecommunication. It started from the first experiences in 1986 with the Videotel service in Emilia Romagna, successively with the Agrivideotel in 90s with more than 1.500 farms and then with web version in 1995, the first real interactive agricultural service based on Internet.

During these years the version of the simulator were changed and improved by Altavia.

In particular during 2006 and 2007 two versions were used: version 1.1 and version 1.2

The version 1.1 was improved during the winter season 2006- 2007. In this way for this study it was possible use the last version in 2006 whilst the new one both in 2006 and in 2007.

4. Discussion and future work

This chapter concerns a simple water balance model for irrigation scheduling and it also details the particular web application for irrigation management for the user. The fundamental idea is that this kind of Decision Supporting Systems, or DSS, should appear as a farm management tool, supporting the farm manager in making decision on irrigations, i.e. whether to irrigate and if so, which crops with how much water.

For these decision, Irrimanager and so IrriWeb® must evaluate the irrigation needs in each crop, by combining information on soil type, crop development stage and water deficit. The farm manager must also compare crops with respect to irrigation needs. The essential information for making these decision is concentrated in one web page (Fig), designed to facilitate the farmer's need for obtaining a quick overview of all crops, which might require irrigation.

The comparison of crops with respect to soil water deficit is supported by intuitively interpreted graphics and facilities to sort crop information by soil moisture that it is shown providing a guide in mm and the irrigation amount.

The model used to calculate the estimated irrigation needs is a black box for the farmer, and facilities to give explanations of expected results are essential for maintaining the farmer's trust in the decision supporting systems.

Explanations are given by a number of graphics describing the development over time for each crop, attainable from navigation buttons on the main page.

The graphics display daily precipitation , real irrigations applied by the farmer as well the two critical thresholds (maximum and minimum) and the simulated soil moisture.

The graphical presentation of the real situation proved a very efficient way of explaining a phenomenon unaware to most users.

IrriWeb® requires inputs of field data by the farmer. This may be a hindrance for getting the farmers to use the decision supporting systems, as using computers is unfamiliar to many farmers. Much effort has been invested in making the input pages as user friendly as possible.

An important aspect is the trade- off between keeping the amount of input data low in order to avoid scaring off new users, and, on the other hand, providing facilities for input of detailed data on soils, crops and weather in order to provide more exact results. This dilemma is attempted solved by organising the input in unique quick start page.

Irrimanager is deliberately designed not to require input data concerning the farmers technical equipment, as this would introduce a need for rather complicated data input pages, which might scare off potential users.

The input page is organised by subject. Each input box concerns a few related data items. It is necessary add more crop if the farmer wants more than one irrigation scheduling. Help is provided not only in the common page before the access (with login and password) but also it is provided close each box in the input and outputs page with a short description of the meaning of them. This is considered to improve the user's understanding of the meaning of the forms, and to improve the overview of the user-supplied data, as only a few data items need to be understood and fields can be to provide input pages field by field.

The innovation in this irrigation service is the mobile-txt face of IrriWeb® . The experience from this first years has been satisfactory in Veneto Region. A relatively small number of users has adopted the system and become frequent users. The system can be successful within short time, since it uses technology already available and known to most potential users.

The technological development within mobile telephony and wireless Internet access will undoubtedly enable more elegant solutions in the near future. If farmers are willing to adopt the new technologies, such solutions may become successful

(Jensen et al., 2003). Concerning direct use by farmers in operational irrigation management, further research is required to reveal the needs and advantages, if any.

There are some main aspects in the further development of this kind of decision supporting system: the scientific validation and the calibration of it in many locations through the comparison between the real values, collected in the fields and the simulated values by the model. In particular the values of: soil moisture and phenological stages.

It's useful using this model to support the farmer in irrigation management but the important is the information would be a correct information.

A correct information, in fact, can be derived only from a scientific using and validating model during the years.

It's important also, considering all the parameters than can be involved in the last irrigation advice because a particular problem of water balance models is that any error will be carried forward and errors will accumulate in the last advice to the farmer.

In fact in the subsequent chapter a carefully description of some important parameters will be done in order to understand which and how they can be affected the results, in particular some aspects to be considered are: evapotranspiration, dual or single crop coefficient, ground water table's effect, adequate phenological development that can be influence root's grow...

Furthermore, Irrimanager works with hourly data of rainfall and daily data of temperature and evapotranspiration, without hourly data the program can be simulate the irrigation advice where other irrigation model can work also without.

Another future development is the application of IrriWeb® during the winter season on some critical zones where there is the strong danger of leaching in the soil (Venice's Basin). So, this model can be used during the winter season, where the water table's pollution is more dangerous than the other period because it's maximum the leaching through the horizons of the soil.

The use of IrriWeb® is low compared to the number of potential users, 0.68% of farmers practising irrigation in Veneto. In this respect, this model is similar to most other agricultural decision support systems (McCown, 2002). The number of users, however, is increasing so it means that the need of support in farm management is increasing as well especially in irrigation scheduling, because the distribution of rainfall during the growing season is changed so the crops require more irrigation supply.

The variability of our climate and especially the associated weather extremes is currently one of the concerns of the scientific as well as the general community (Climate Research Committee, 1995). The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models, agro meteorology and the concerns society, like in this case and at the same time it shows how critical is the role of the researchers involved in the development of modelling concepts as well as the evaluation of their models and decision supporting systems for on-farm applications.

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Chapter 5

APPLICATION OF THE MODEL

1. Introduction

The great challenge for the coming decades will be the task of increasing food production to ensure food security of the steadily growing population, particularly in countries with limited water and land resources. While on a global scale water resources are still ample, serious water shortages are developing in the arid and semiarid regions. An increasing number of countries face serious water deficiencies as existing water resources are fully exploited. The dependency on water for future development has become a critical constraint for development.

Over 30 arid and semi-arid countries are expected to be “water scarce” by 2025, meaning an annual water availability of less than 1000 m³ per capita annually, which will slow down development, threaten food supplies and aggravate rural poverty. The situation is also aggravated by the declining quality of water and soil resources, caused to a great extent by human activity (Smith, 2000).

Anyway water availability is the single largest determinant of agricultural production and is a major plant-limiting factor in other ecosystems, such as forests (Zierl, 2001). As a result, numerous irrigation scheduling and water balance models have been developed (Clemente et al., 1994).

These models have been used for both research purposes and as management tools. The end purpose of the model influences the modelling approach used. Models used for research purposes generally represent the system and underlying processes in greater detail than do management models. However, even within the existing different categories of models, models differ in their assumptions and representation of water balance processes (Maraux et al. 1998) and in their input data requirements (Olejnik et al., 2001).

Various methods and tools for scheduling irrigation have been developed ranging from those based on the water status of the soil or plants, to those that use a model to predict the soil water balance. Jensen et al. (1961) were the first to develop an irrigation-scheduling program using meteorological data to calculate crop water-use. Many variations of this approach are now in use. Generally speaking these kind of tools have a great potential to improve the management of the water resources. Nevertheless prior of widespread application it is necessary to validate the model in the environment where it has to be applied.

This chapter describes the application and validation of Irrimanager in a maize's crop located in Legnaro, in North East of Italy, in 2006 and 2007 with version 1.1 and version 1.2, that is the last version of Irrimanager but also in Shepparton, in

Victoria State of Australia, in 2004-2005, always in a maize's field with the version 1.2.

In particular, objectives of this work are: verifying if the output of Irrimanager are reliable about the information of irrigations scheduling; testing in the field conditions phenology development and soil moisture (validation); individuating the eventual critical aspects that can affect the correct information; suggesting adequate modifications to Altavia srl.

In fact, since Irrimanager is a commercial simulation model, it was not duty of this study to implement the modification of the model.

In Australia, a comparison with another simple water-budget model, developed by the Department of Primary Industries, located in Kyabram, Victoria State, is provided in this work. The model is designed to schedule the irrigation, like Irrimanager, even if it hasn't got a "public face" because at the moment it is available only for scientific purposes.

In this way, the application of the two different Irrimanager versions in Italy was studied and at the same time it was also used in a different country, Australia, with a totally different situation from meteorological and soil records. The use of Irrimanager in another country helps the validation and provides information on its flexibility and adequacy to be applied under different agriculture conditions.

2. Materials and Methods

2.1 Application of the model in Italy

2.1.1 Crop location and management

Maize crop, grown at the university farm in Legnaro (45°20'26" N, 11°58'0"), Padova, in North East of Italy, was cultivated in two different fields in 2006 and in 2007.(Fig. 1).

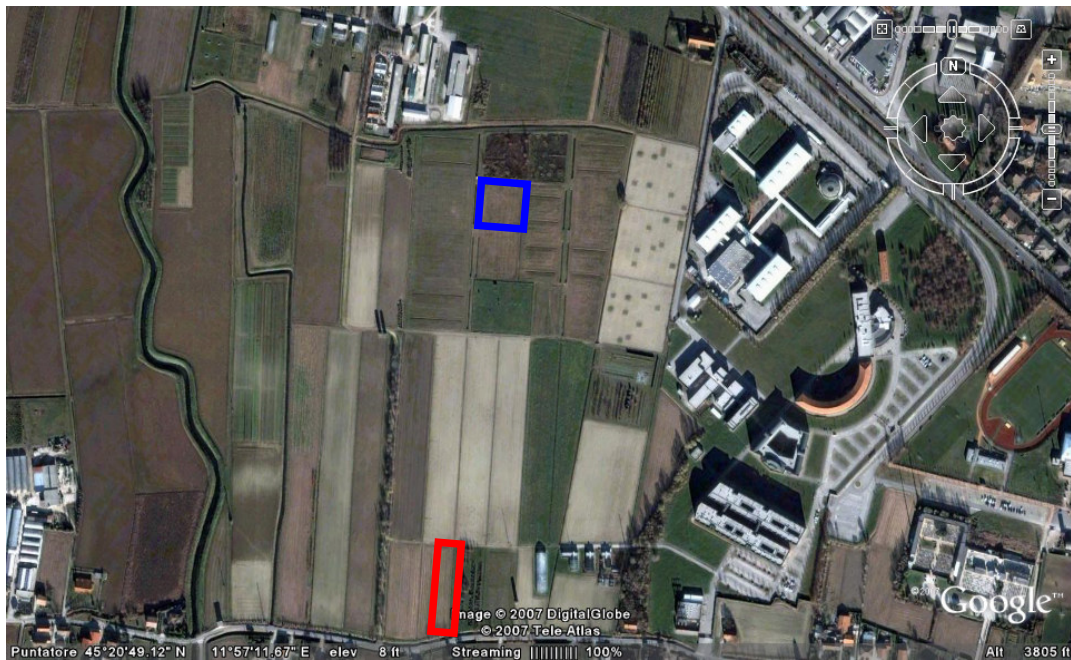


Fig.1 - The study area and locations of field measurements in Legnaro (Padova) in 2006 (red rectangle)and 2007 (blue rectangle) (Google Earth, 2007)

No one of these maize crops were irrigated during both years. Maize's crop in 2006 and in 2007 were both sown in early April and harvested in early September and the FAO class was the 600 one.

The textural class of the soil was determined by hydrometer method using USDA soil texture classification. Soil samples were taken from three depths (0-25, 25-50, 50-100 cm). The dominant texture class of soil was loam for the entire experimental plots . (Table 1)

depth (cm)	2006			2007		
	Sand (%)	Loam(%)	Clay(%)	Sand (%)	Loam(%)	Clay(%)
0-25	36	49	15	34	49	17
25-50	36	49	15	34	49	17
50-100	48	30	22	50	32	18

Tab. 1 - Soil texture

All the agronomic details are given in Tab.le 2.

	2006	2006
<i>Irrigation method</i>	No irrigation	No irrigation
<i>Variety</i>	Costanza, Pioneer	Costanza, Pioneer
<i>FAO class</i>	600	600
<i>Previous crop</i>	Soy	Soy
<i>Sowing date</i>	1 st April	5 th April
<i>Harvest date</i>	29 th August	12 September

Tab. 2 - Agronomic details in 2006 and 2007

The depth of the local groundwater table was measured using one permanent freaticometer installed close to the fields, to a depth of 3 m. Measures of groundwater were recorded every two weeks, and during the maize's growing season its average was about 1,5 m in both years.

2.1.2 Climatic data

Daily values of the weather variables such as: solar radiation, maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall for the experimental period were obtained from the automatic ARPAV weather station installed close to the experimental crop field. Evapotranspiration (ET_0) was determined from Penman Monteith formula.

It is also available hourly rainfall in order to prepare the file for Irrimaneger simulations, these records are automatically sent to Altavia server everyday during the irrigation season.

Meteorological records were analyzed in Legnaro, starting from 1953 to investigate about the local trend of these (see Chapter 2). In particular evapotranspiration of 2006 and 2007 were calculated with two methods, Penman-Montieth and Hargreaves, and then the obtained values were compared.

2.1.3 Field observations of phenology stage

Phenology stages were observed in 2006 and 2007. The observation were made with the International BBCH scale (see Chapter 3). 28 plants were selected and labelled immediately after the emergence stage, in this way it is possibly effectuating the observations always on the same plants without any possibility of error.

Observations were conducted every week or every 15 days, depending on the phenological stages and it permitted to have the observation, at least, of the main phenological stage on maize.

These observations were used also for the Phenological Network, in fact Legnaro is actually a site of the Network with maize during the summer season.

2.1.4 Field samples of soil moisture

The water soil content was measured with gravimetric described by Black et al.(1965) at each monitoring year. First sampling was done at the time of crop sowing and subsequent samplings were taken until harvesting time. Samples were collected from 0-0.05 cm, then at 0.20cm intervals to 0.80cm, every 2 weeks - from sowing date until harvesting time. For each different depths, 4 samples were collected, placed in hermetically sealed containers, and taken directly to the University laboratory in order to analyse them the same day.

To determine soil moisture for a particular sample, the water mass must be determined by drying the soil constant weight and measuring the soil sample mass after and before drying. The criteria for a “dry soil sample”, is one which has been dried to constant weight at an air temperature between 100-110°C (105 °C is typical). This temperature range is based on the boiling temperature of water, and does not consider the physical and chemical characteristics of the soil.

The results from soil moisture's samples in this way were expressed in % of water in their weight; then these values were converted in mm of water in the same depth calculated by Irrisweb. This depth depends on the development stage of the crop: that is about 15 cm at the initial stage until 50 cm at the ending stage.

In order to estimate the quantity of water in mm, bulk density's method was used. The average bulk density derived from 6 undisturbed samples was 1.47 g cm^{-3}

The values obtained from these samples were compared with those simulated by the model.

2.1.5 . Model simulations

In 2006 version 1.1 and version 1.2 (the latest version) were used. Comparison between observed and calculated values of soil moisture and phenological stages was carried out on the same year by using two different versions.

Version 1.1 was improved during the winter 06-07 in order to estimate better the contribution of groundwater Table on the soil moisture, because during 2006 some observations about the non good estimation of groundwater Table were noted by other regions that are using and validating the model too.

In 2007 only version 1.2 were used and comparison between observed and calculated values of soil moisture and phenological stage was carried out too.

2.1.6 Statistical analysis

Differences between measured and Irrismanager simulated values of soil moisture with the two different versions and in the two years were analyzed by the following statistical quantities (Loague and Green, 1991; Duwing et al., 2003):

Nash efficiency (NE) coefficient (Nash and Sutcliffe, 1970), root mean square error (RMSE) and mean bias (MB) defined, respectively, as:

$$\text{NE} = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

$$\text{RMSE} = \frac{100}{\bar{O}} \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$$

$$\text{MB} = \frac{\sum_{i=1}^n (P_i - O_i)}{n}$$

Where O_i and P_i are the observed (simulated) and calculated values, respectively, \bar{O} the mean of the observations and n is the number of samples. NE, RMSE and MB should be as close as possible to 1, 0 and 0, respectively.

2.2 Application of the model in South Australia

2.2.1 Model description

The Australian model is a simple FAO 56 spreadsheet model that uses a water-budgeting approach to schedule irrigation of maize for pasture in Victoria State. The model was developed by the Department of Primary Industries of Kyabram, Australia (Greenwood et al., 2007)

The model was tested and performed well at three maize crops in two places not far from Kyabram, both irrigated, in 2003-04 and in 2004-05. For this study only the last maize crop was utilized to compare the model with the Italian one.

Note that in the Kyabram's model:

Evapotranspiration: crop evapotranspiration was calculated by multiplying the reference crop evapotranspiration by a dual crop coefficient, FAO 56 method (Allen et al., 1998). Daily reference evapotranspiration was collected by the automatic weather station. Crop coefficients for different stages of maize growth (Allen et al. 1998) were adjusted for the frequency of wetting of the soil surface, on local weather conditions (mainly wind speed and relative humidity).

The FAO procedure has provision for using either single or dual crop coefficients. The dual crop coefficient procedure, where there are separate transpiration and evaporation coefficients, is recommended for daily calculations of crop evapotranspiration for specific fields of crops for specific years. In this model the spreadsheet provided in Annex 8 of Allen et al.(1998) to estimate the daily evapotranspiration for maize crop was used.

Water balance: a water balance for maize crop in 2004-2005 was constructed using measured values of irrigation, rainfall and estimated crop evapotranspiration.

Soil water deficits and drainage: soil water deficits was calculated on a daily basis by the FAO 56 spreadsheet. Deep drainage was also estimated using the water balance equation, by this spreadsheet model.

2.2.2 crop location and management

For this work one maize crop, grown on dairy farm, was monitored in 2004/05, about 11 km south of Kyabram (Fig.2 a and 2 b).

The crop area covered 3 soil types – Shepparton fine sandy loam, Lemnos loam and Type 2 soils –a s mapped by Skene and Poutsma (1962). Monitoring sites were located in the area of Shepparton fine sandy loam, which is red sodosol (Isbell, 1996) also known as a red-brown earth (Stace et al.1968).

All management, including irrigation, of the crop was provided by the co-operating farmer. Agronomic details are given in table 3.



Fig 2 - Australia Victoria state's map

2004-2005	
Irrigation method	Centre pivot
Variety	Pioneer, 36H36
FAO class	600
Previous crop	Barley grown for silage and harvested 05/11/2004

Sowing date

17th November 2004

Harvest date

21st March 2005

Tab. 3 - Agronomic details in Kyabram

2.2.3 Climatic data

At crop location, an automatic weather station was used to measured rainfall, air temperature, humidity, global radiation, and wind speed and direction at 15 minute intervals. The weather station was located as close to the crop as practical, but at least 30 m from the crop. Values of the reference crop evapotranspiration (ET_0), on a daily time interval, were obtained from SILO of South Australia (<http://www.nrw.qld.gov.au/silo/>), using the modified Penman- Monteith formula.

Any missing data (<5%) caused by equipment failure or operator error were substituted by data collected from a similar weather station at the Department of Primary Industries (DPI), Kyabram.

2.2.4 Comparison between Irrimanager and Kyabram's simulations

Inputs and outputs between two models are very similar but however not the same. Note that Kyabram's model hasn't a Internet availability or a server in which who is interest can work: it is a easy excel sheet in which the user has to put some data of the fields in order to calculate the water balance and so the irrigation needed. In particular it requires daily meteorological data.

In Table 4 these differences are shown.

INPUT	<i>Kyabram model</i>	<i>Irrimanager Model</i>
<i>Sowing date</i>	*	*
<i>Crop</i>	*	*
<i>Texture</i>		*
<i>Daily records of temperature and evapotranspiration</i>	*	*
<i>Hourly records of rainfall</i>		*
<i>Water Tab.le</i>		*
<i>Irrigation system</i>		*
<i>Kind of water balance (with irrigation and after the star stage or without for one year)</i>	*	*
<i>End date of water balance</i>		*

Tab. 4 - Comparison between the input of the two models

An appropriate meteorological file was prepared to create a simulation in Kyabram with Irrimanager .

The meteorological file was created in an excel format with daily records of minimum, maximum, mean temperature and daily ET_0 and hourly records of rainfall. The file was sent to Altavia to be inserted in the program and to permit the creation of a water balance scenario in Australia.

Water balance simulation model with Irrimanager was created using the option of “water balance model after start stage”, in this way the model simulates the effective irrigation needs

In order to have the best comparison between the two models, some input in Kyabram’s model were modified: in this way, minimum and maximum roots’ depth (0.15 to 0.50 m) and available water (60 mm/h) input of the two models were set equal.

Simulations were carried out and some of the main outputs of the two models were analyzed to compare the results, in particular: ET_m (actual evapotranspiration), drainage, depletion and total amount of irrigations, number of net irrigations need..

The output's comparison between the two models was estimated with the statistical linear regression and the correlation coefficient.

3. Results

3.1 Irrimanager in Italy

Two different depths of ground water table are used in simulating results (no water table and the real value, about 1,5 m) in both years, 2006 and 2007

There is a close match between simulated and measured phenological observations to emergence and maturity stage. The linear regression had a good coefficient of determination (r^2) of 0.87 in 2006 and 0.98 in 2007 (Fig 3 and 4).

It confirms that the phenological part of the model simulates well the developing of the crop

Values of simulated and measured soil moisture in 2006 as a function of time with version 1.1 and version 1.2 are given in Fig. 5 and Fig. 6 whilst values of rainfall and simulated and measured phenology stage in Fig. 7 and 8.

In both versions in 2006 the trend of *soil moisture* was similar and in particular constant and low at the beginning of the year and then it increased after about 121 Julian date, because of the roots' depth.

The two different depths of ground water table affected soil moisture's values, in fact the simulation without ground water table has got lower values than those one with 1,5 m of depth.

However there is a difference between the two versions used in the same year: version 1.1 has values lower than version 1.2 and also it has got lower difference between the soil moisture values simulated with two different depths.

The most significant difference in the increasing soil moisture values is at about 150 Julian day and so also the differences between the two model's results.

Measured field values are more constant than the simulated ones and they are closely connected with the values of rainfall during all the year.

In 2007 only version 1.2 was used. The soil moisture trend is the same as in 2006, i.e. low at the beginning and then, after the growing of the roots and the increasing of rainfall the values are higher (Fig. 9). The difference between the two depths of ground water Table is also in the last version lower in the simulation with a ground water Table of 1,5 m than that one without.

In both case Irrimanager has values higher than the measured one during the growing period. The measured one, however, are no constant like in 2006 but anyway they remain closely connect with the rainfall's trend during all the year (Fig 10).). Phenology stages are given in Fig.11.

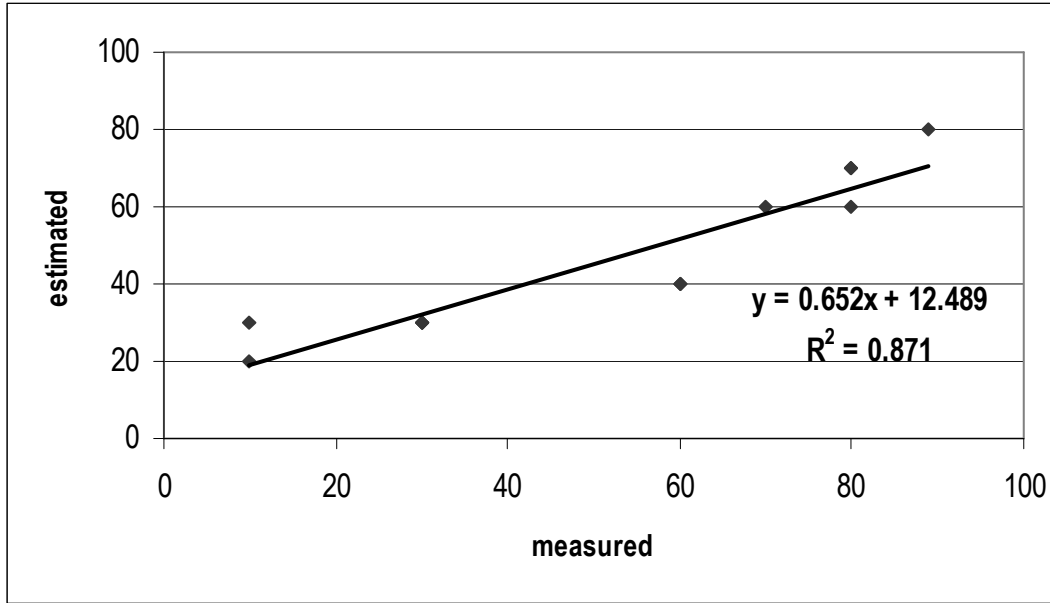


Fig 3 – phenological stage: correlation measured vs estimated in 2006

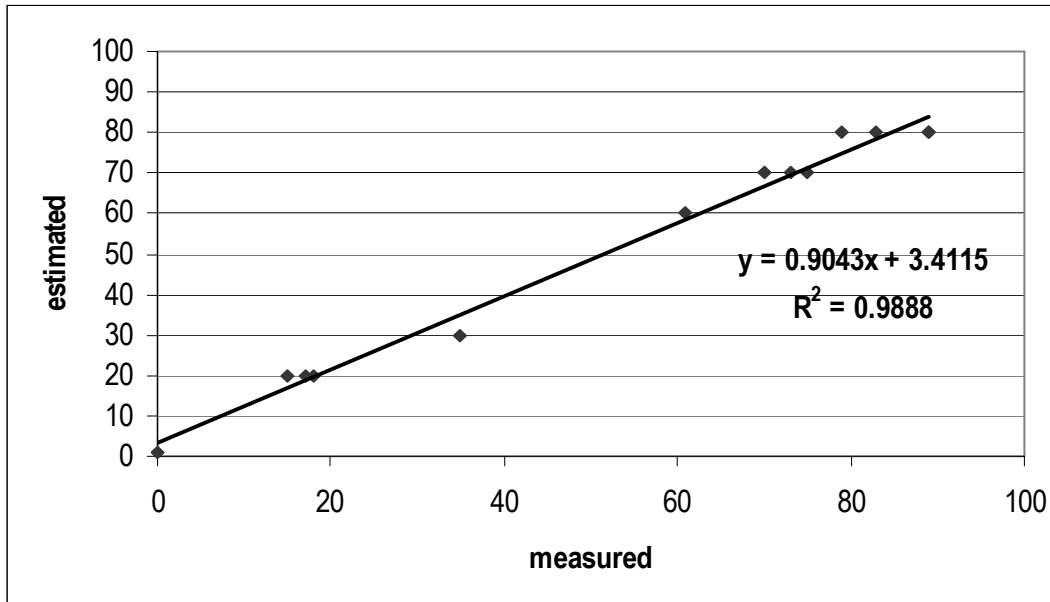


Fig 4 – phenological stage: correlation measured vs estimated in 2007

Values of NE, RMSE and MB are given in Tab. 4 for soil moisture. All these results show that the predictions of soil moisture by Irrimanager match collected data reasonably well for the version 1.1 and 1.2 in 2006 but not well for the version 1.2 in 2007. Anyway, 2006 results having the best simulation between the two versions.

MB values (Tab. 5) indicate that Irrimanager had a slight tendency to underestimate soil moisture in 2006 whilst to overestimate in 2007. However, this misfit may be attributed to changes of the new version or to mistakes of sampling.

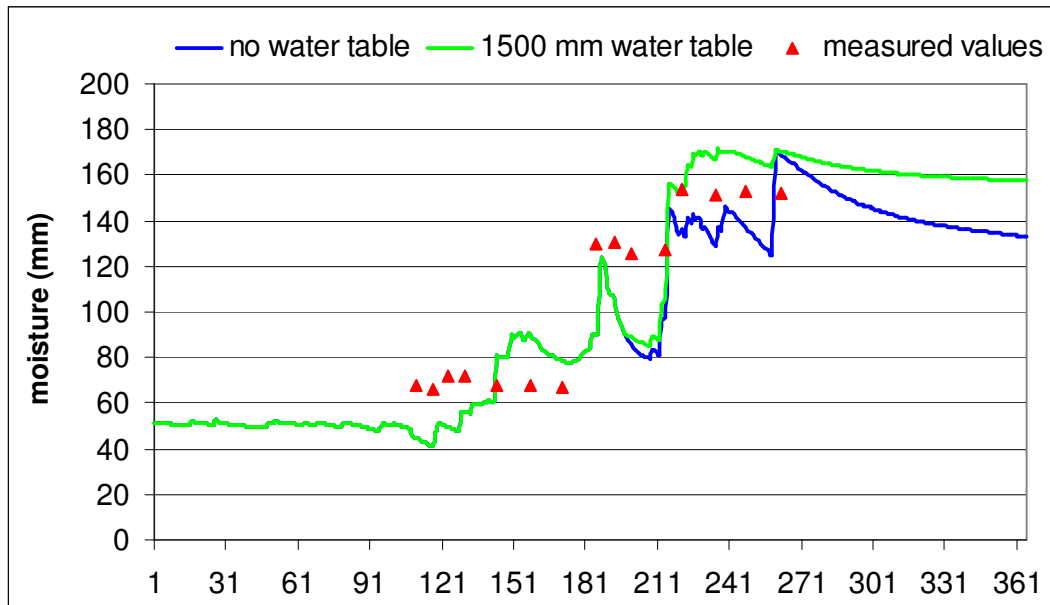


Fig. 5 - Estimated and measured soil moisture's values at two ground water Table's depths in 2006 version 1.1

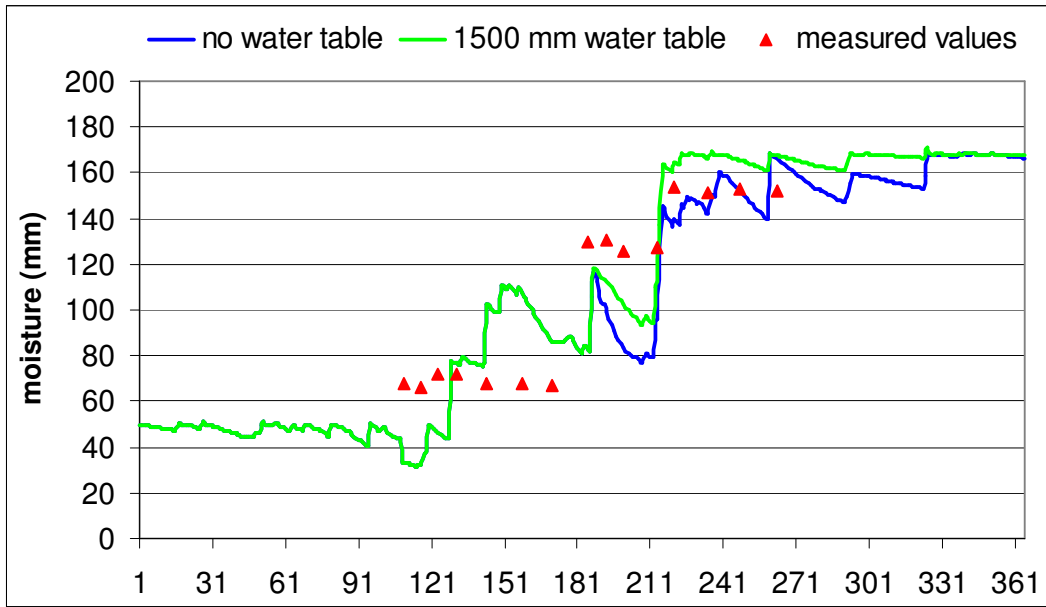


Fig. 6 - Estimated and measured soil moisture's values at two ground water Table's depths in 2006 version 1.2

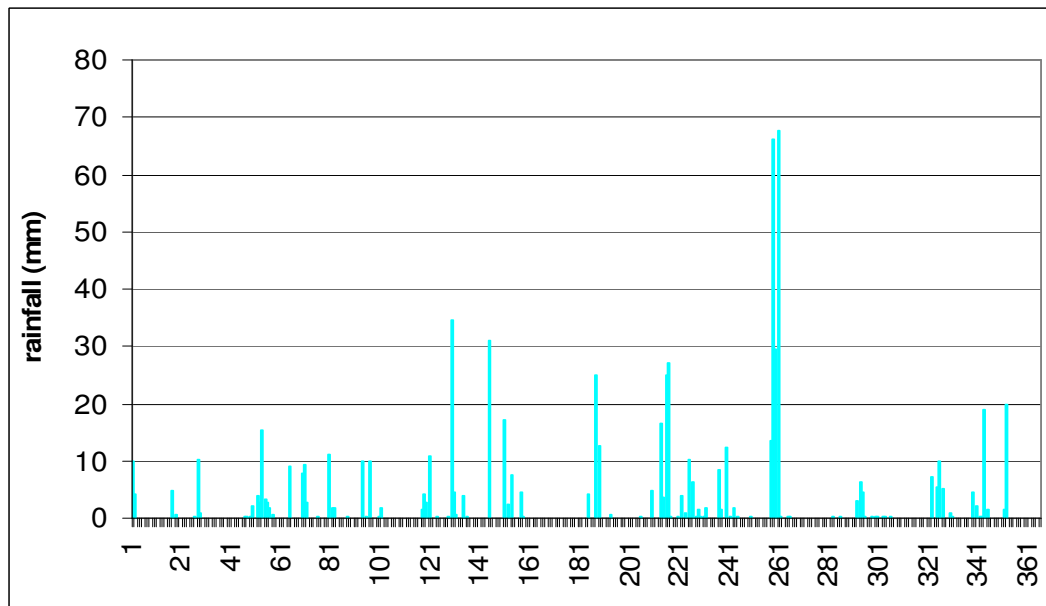


Fig. 7 - Rainfall 2006

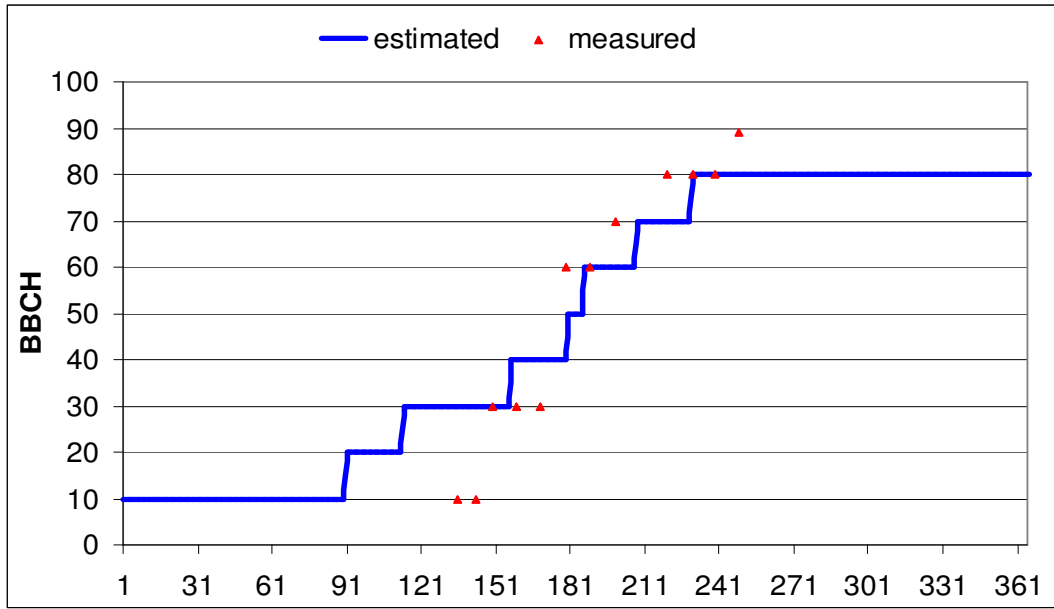


Fig. 8 - BBCH observed and estimated values in 2006

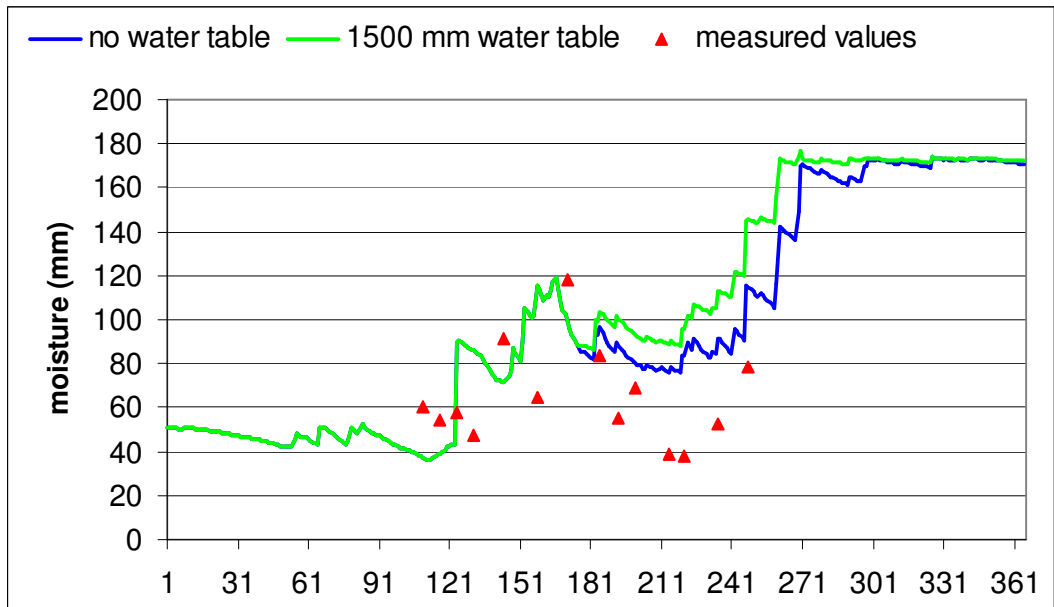


Fig. 9 - Estimated and measured soil moisture's values at two ground water Table's depths in 2007 version 1.2

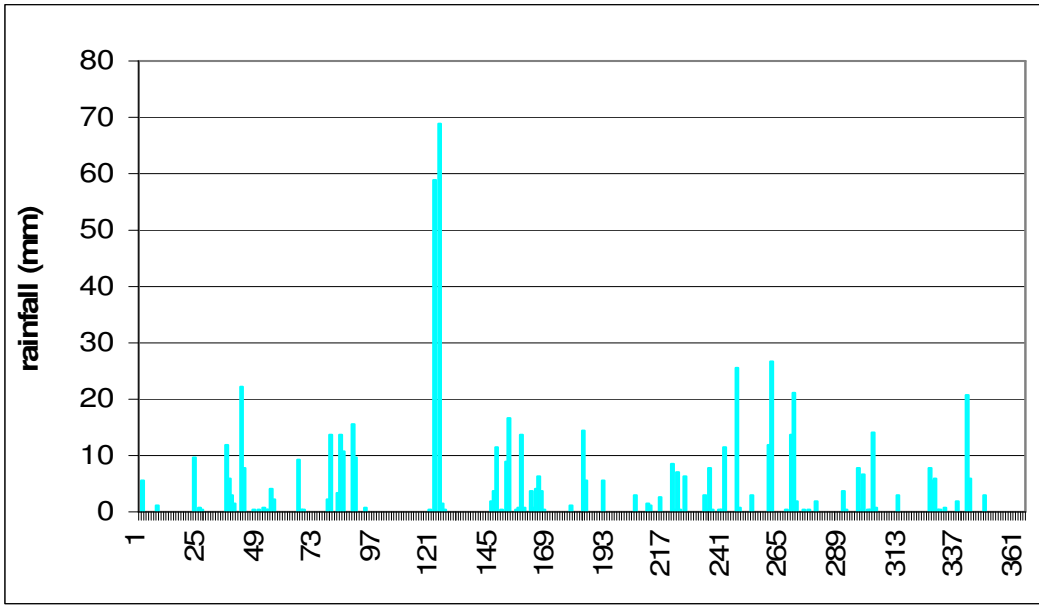


Fig. 10 - Rainfall in 2007

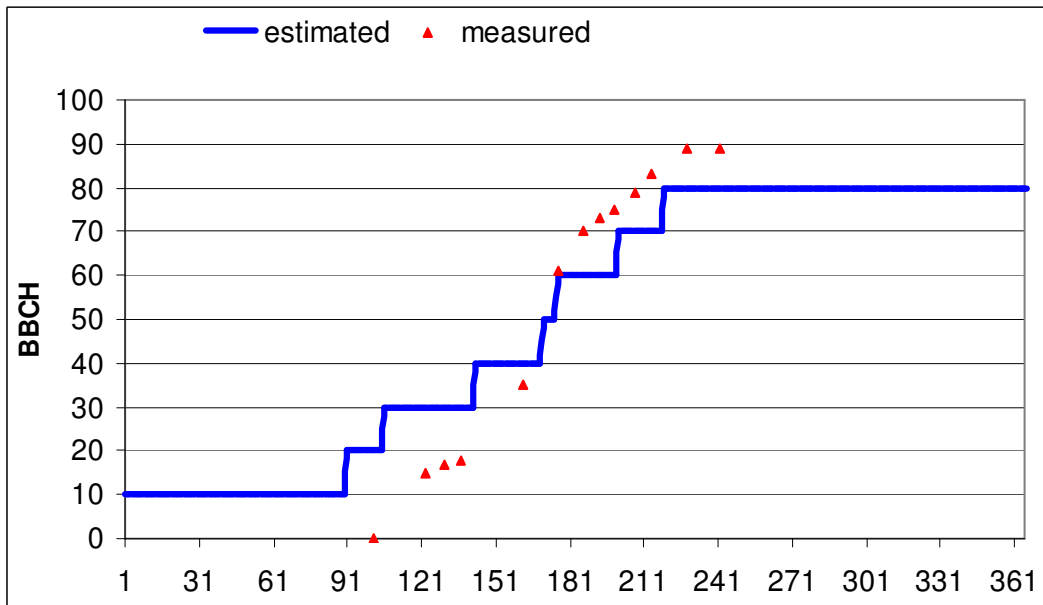


Fig. 11 - BBCH observed and estimated values in 2007

	V 2006	1.2	V 2007	1.2	V 2006	1.1
Number of observations, n	15		14		14	
Observed mean (mm)	107		65		107	
Mean Bias, MB (mm)	-0.105		0.117		-0.118	
Nash Efficiency, NE	0.43		-0.03		0.54	
Root mean square error, RMSE	0.30		0.29		0.24	

Tab.5 - Values of MB, NE and RMSE between observed values of soil moisture and those predicted by the Irrimanager model with the two versions in the two years

The comparison of the values of potential evapotranspiration between Penman-Monteith method and Hargreaves formula shows a good correlation both 2006 and 2007, with $r^2 = 0.85$ (Fig 12 and 13).

The means and standard deviations were calculated for both years and compared by means of the Student t-test. $p < 0.05$ was considered significant (Tab. 6). However Hargreaves equation overestimated ET_0 (Fig. 14 and 15) and so utilizing Hargreaves formula instead of Penman-Monteith (that is the formula of the model), the total amount of water requirement would be higher of about 170 mm, that is the mean different between the cumulative potential evapotranspiration at the end of the maize growing season.

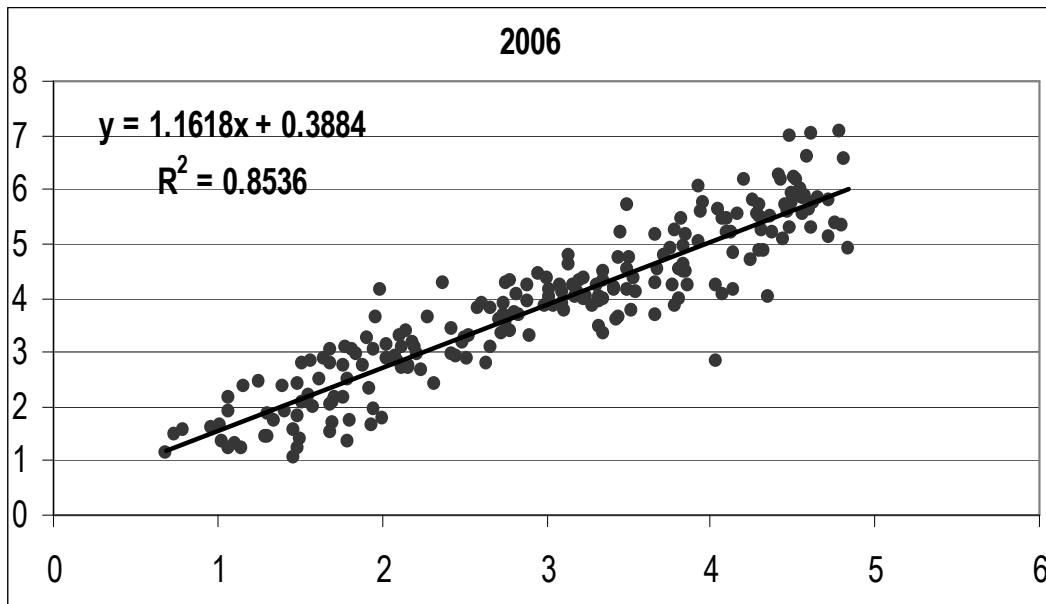


Fig. 12 -Penman vs Hargreaves in 2006

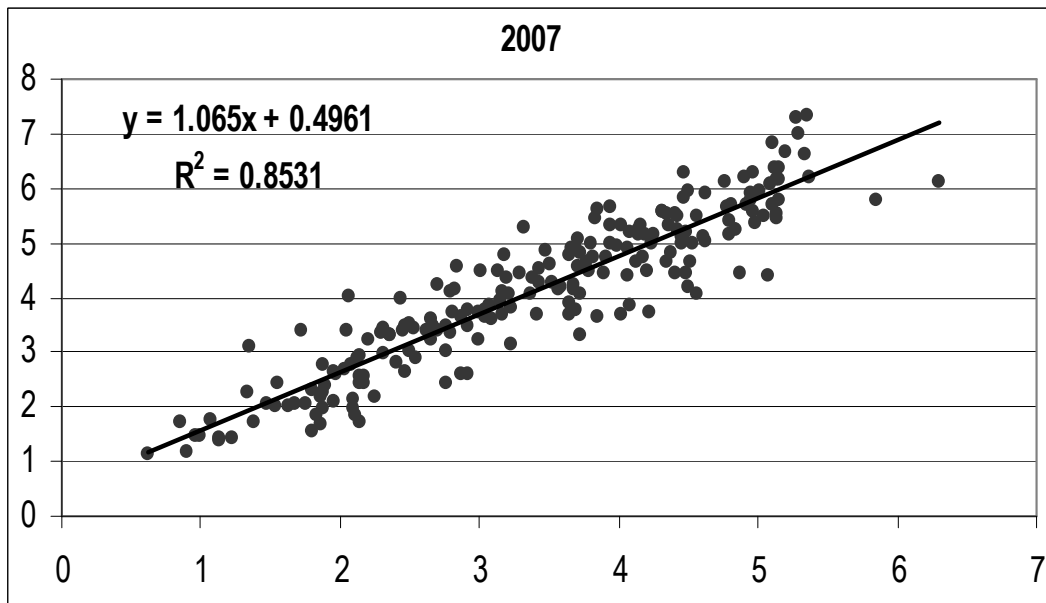


Fig. 13 - Penman vs Hargreaves in 2007

	2006		2007	
	Penman-Montieth	Hargreaves	Penman-Montieth	Hargreaves
n° observations	214	214	214	214

mean	3.0	3.9	3.4	4.1
standard deviation	1.1	1.4	1.2	1.4
t	7.03		5.8	
Degrees of freedom	426		426	
p (with p<0.05)	0.00		0.00	

Tab. 6 - T test

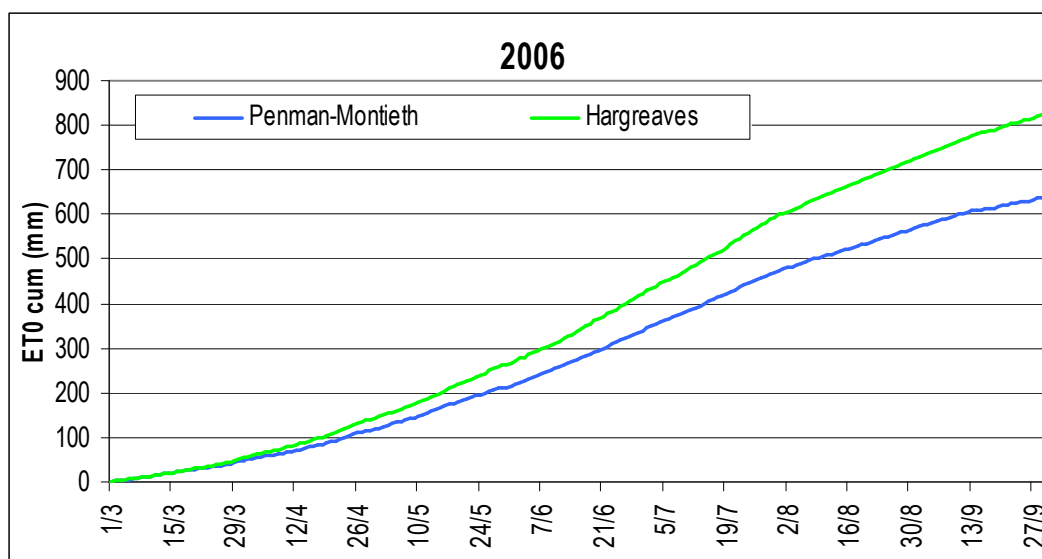


Fig 14 - Cumulative potential evapotranspiration during maize growing season (1st March-30th September) calculated with Penman-Montieth and Hargreaves

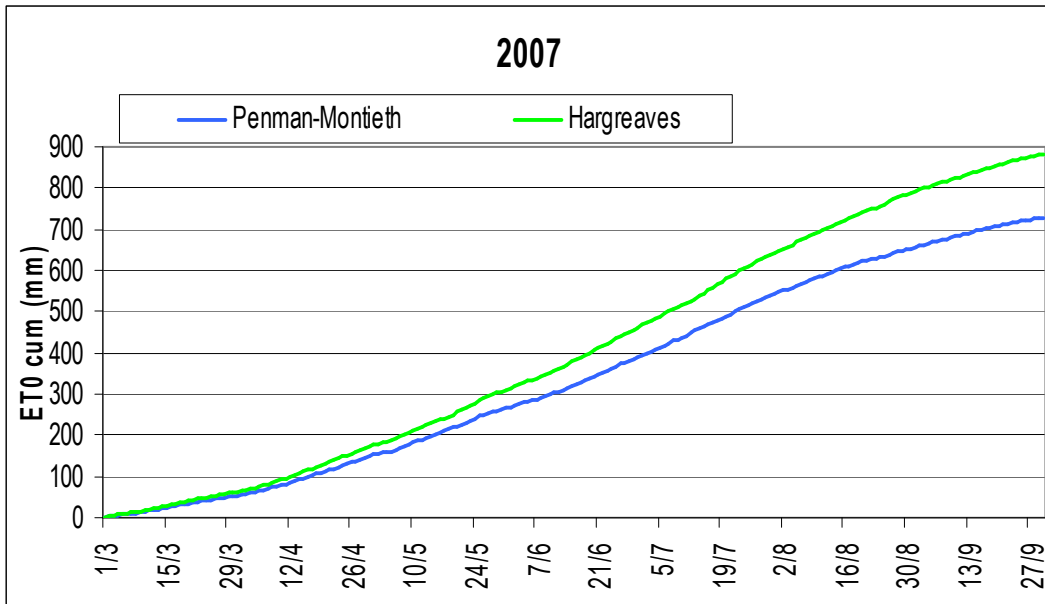


Fig 15 - Cumulative potential evapotranspiration during maize growing season (1st March-30th September) calculated with Penman-Montieth and Hargreaves

3.2 Irrimanager and Kyabram's model in Australia

The soil water balance component of Irrimanager software was run in Australia and then the output were compared with the output coming from Kyabram's model. In particular:

- Root depth
- ET max
- Drainage
- *Irrigation needs*

ET max, drainage and irrigation's trend has higher values using Kyabram r than Irrimanager model (Fig 16 and 17)

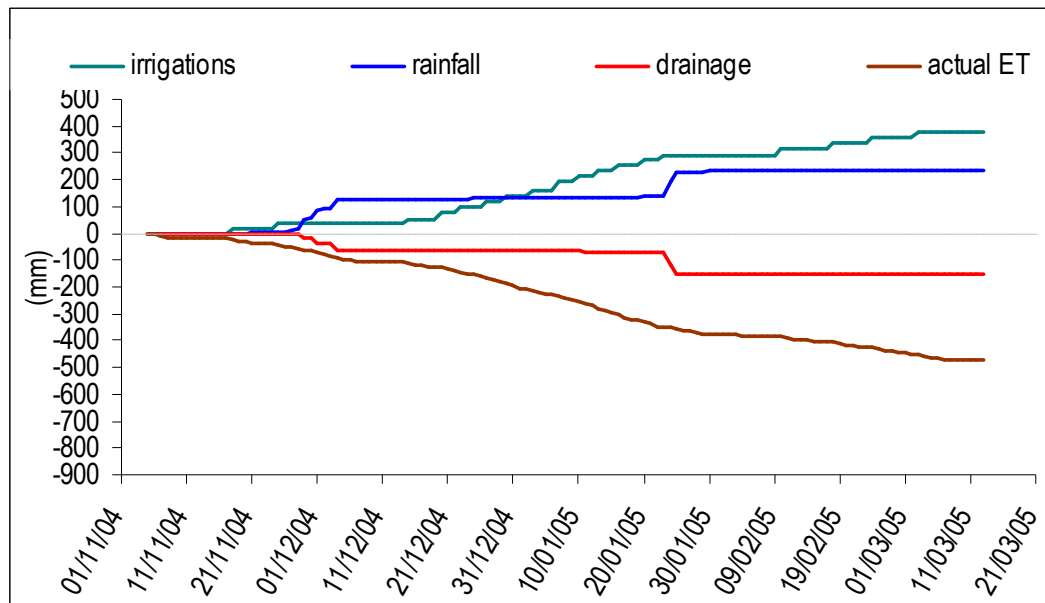


Fig 16 - Kyabram's output

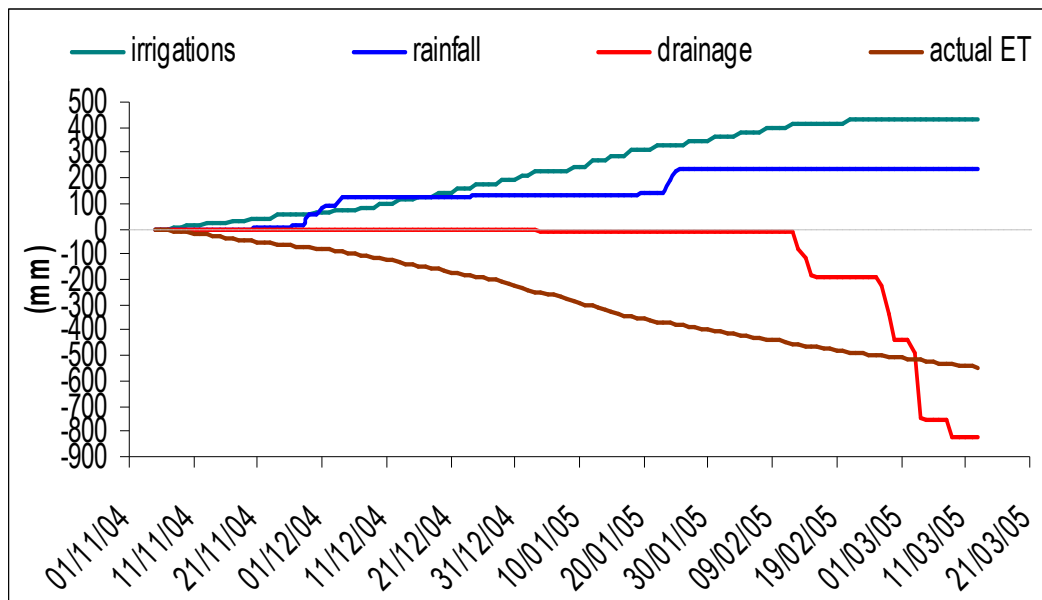


Fig 17 - Irrimanager output

A canonical statistical analysis (Tab. 7) describes the correlation among the output from the two models. Root depth' and ET_m values had a good determination coefficient whilst irrigation not. However root depth had also a significant result in T-test. The determination of K_c with different method had an a critical effect in these values.

	Root depth	ET_m	Irrigation
r^2	0.97	1.0	0.1
R	0.94	1.0	0.0
Degrees of freedom	256.0	256.0	256.0
T test	**	n.s.	n.s.

Tab.7 - statistical analysis of output of two models. *,** and *** significant level, $p < 0,05$, $0,01$ and $0,001$ respectively.

Therefore an additive comparison of output irrigation is given in Tab. 8. In fact, starting from the other higher output, the simulated values of the net irrigations are higher than Kyabram's ones: during the whole growing season there was a not significant differences of total amount of irrigation (only about 45 mm) and interval of irrigations (3 days for both models). A slight difference was found in the date of initial and last irrigation (about 10 days) and a great one in the number of applications (11 more in Irriweb).

	tot amount net irri (mm)	n°net irri	average irri (mm)	Interval irri (d)	initial date	last date
IRRIWEB	388	30	13	3	18-nov-04	03-mar-05
KYABRAM	343	19	19	3	28-nov-04	13-mar-05
	45	11	6	0	10	10

Tab. 8 - Detailed comparison of irrigations ouput

Irrimanager estimates 30 applications whilst Kyabram only 19. This is probably connected with the kind of irrigation system, because the change of irrigation system can change the maximum and minimum threshold of application. In Irrimanager one of the input is the irrigation system because different systems have got different threshold.

The number of application it also closely connect with the MAD (management allowable soil waterdeficit).

The irrigation applied in fact is when the soil water deficit reached a MAD (maximum available depletion)threshold level equivalent to a percentage of the readily available water (RAW). By selecting different MAD levels (%) the number of can be modified but in Irrimanager this is not possible

4. Conclusions

In this chapter, the values of soil moisture and phenology of Irrimanager model have been compared against measured data .

In Italy two years study of Irrimanager were carried out in the university farm's field, using maize crop. Satisfactory agreement was obtained between measured and Irrimanager values of soil moisture and phenology stage in 2006 with version 1.1 and 1.2. but not for soil moisture in 2007 with version 1.2.

Therefore Irrimanager was used in West Australia and the results were compared with the output coming from another model.

Both models are based on a similar set of water balance input even if calculated $E_{t,m}$ was obtained from two different methods; additionally in Irrimanager phenology stage is simulated; however output of irrigation needs coming from the two models had a good correlation even if Irrimanager had higher values than Kyabram's one.

Results demonstrate the discrete ability of Irrimanager to simulate good values of soil moisture and phenology, future research will keep going with the validation of the simulator in Legnaro. The model must be calibrated and tested also for different climatic conditions in order to obtain the best possible irrigation advice to help the farmer.

In particular study of the effect of groundwater table, crop coefficient with FAO 56 and the use of Hargreaves in the water balance formula will be consider to analyze the possible effects of them on irrigation need calculation during the summer season in maize crop.

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<http://www.bom.gov.au/silo/>

Chapter 6

GENERAL CONCLUSION

The application of irrigation simulation model has become more acceptable in the agricultural community during the last few years because climate change is playing a key role in the distribution of the rainfall during the summer season. The farmer needs to be helped and supporter in their management.

For any application of irrigation model or anyway crop model, a lot of important data coming from agro meteorological science are critical inputs. It is important that these data will keep continue to be collected for all regions where the agricultural production is an economic source of income.

Crop simulation models will never be a substituted for experimental data collection. Field data continue to be needed for model evaluation as well as for improvement of the models. However there will be more scope for the application of crop simulation models to help provide guidance in solving realm world problems related to agricultural sustainability, food security, the use of natural resources and protection of the environment.

Agrometeorology will be critical component of all these applications to help understand the impact of weather variability and the uncertainty of future weather conditions it will play a pro-active role in promoting sustainable development in the future and a key role in the looming global water crisis.

A well coordinate research thrust with emphasis on resource management will better serve the cause of sustainability in the long term running.

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With love Alessandra