Beiträge zur Hydrogeologie / 57 / Seiten 87–102 / Graz 2010

Irrigation Water Requirements Based on Crop Water Needs – Application of the CropSyst Model in the Region Friuli-Venezia Giulia (Italy)

Bestimmung der Bewässerungsmenge aus dem Wasserbedarf von Pflanzen – Anwendung des CropSyst-Modells in der Region Friaul-Julisch Venetien (Italien)

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Content

1. Introduction

The main objective of this study was to develop a methodology to optimize the water resources for irrigation using the effective crop water requirements of maize, soybean

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(year 2007 only) and grapevine for the cropping season 2006 and 2007. The research study carried out in the framework of "Competence Network Water Resources and their Management" (Knet Water) has been applied to five farms with different pedoclimatic characteristics, but all representative of the Friulian Plain (Pianura Friulana). The Friulian Plain, of the Region Friuli-Venezia Giulia in Italy is characterized by intensive agricultural activities with a usable agricultural area of 218,812 ha, 145,400 ha (66.45%) of which are irrigated. Another important aspect was the calculation of the difference between the effective amount of water used during the traditional irrigation practices and the optimal amount of water necessary to the irrigation scheme to satisfy the crop water requirement (CWR) during the growing seasons. The CWR is the amount of water required by the cropped fields to compensate the evapotranspiration losses. To achieve the goals of the study the cropping systems simulation model CropSyst was used.

2. Investigation areas

The cropping systems simulation model CropSyst has been applied to four experimental and demonstrative farms belonging to ERSA (Regional Agency for Rural Development) and to one private farm (Fig. 1) with the following crop, soil and geographical characteristics:

1. The ERSA "Azienda A.I.D. Rinascita 6.5.1976" in Spilimbergo (Province of Pordenone) is an experimental/demonstrative farm located in the typical shore environment of the River Tagliamento. It is characterized by very gravelly, highly draining loamy sand soils that are mainly devoted to fruit and vineyard productions, but also with a minor presence of cereal crops. The farm is also equipped with several experimental lysimeter stations. Two of these stations are located in a cereal-farming field, the other in an experimental vineyard formed by rows of different grapevine varieties (Tocai, Cabernet Sauvignon and Chardonnay). The investigations have been focused on maize crops and the Tocai grapevine variety.
2. The ERSA "Azienda agricola Marianis" in Piancada di Palazzolo dello Stella (Province of Udine) is an experimental farm used for cereal crops and livestock farming. It is located on sandy clay loam soils that are representative of the lower Friulian Plain. The study area has been located in an experimental field (maize/soybean) with a tubular drainage system laid at a depth of 100 cm and connected to an automated draining water sampler.
3. The ERSA "Azienda Dr. Francesco Ricchieri" in Fiume Veneto (Province of Pordenone) is devoted to the breeding of bulls for the Pezzata Rossa Friulana breed. Located on loamy soils with sub-alkaline pH, it produces cereals and leguminosa for in-farm use. A cereal-cultivated field (maize/Italian ryegrass – maize/maize) equipped with an experimental lysimeter station has been selected for the investigations.
4. The "Azienda F. Toros" in Cormòns (Province of Gorizia) is a private ownership of the Toros' family. Located in the DOC "Collio" district, it is only used for high quality wine production. Its soils are neutral in pH and characterized by a loamy texture. The Toros farm lacks lysimeters and thus the investigation has been carried out in a Pinot Grigio vineyard located near the private well of the farm.
5. The ERSA "Azienda frutti-viticola Pantianicco" in Beano di Codroipo (Province of Udine) is used for experimenting in the fruit and vineyard-farming field. The field is characterized by very gravelly, highly drained loamy sand soils. No lysimeter occurs and the investigation has been carried out in a Pinot Grigio vineyard located near a local irrigation well.

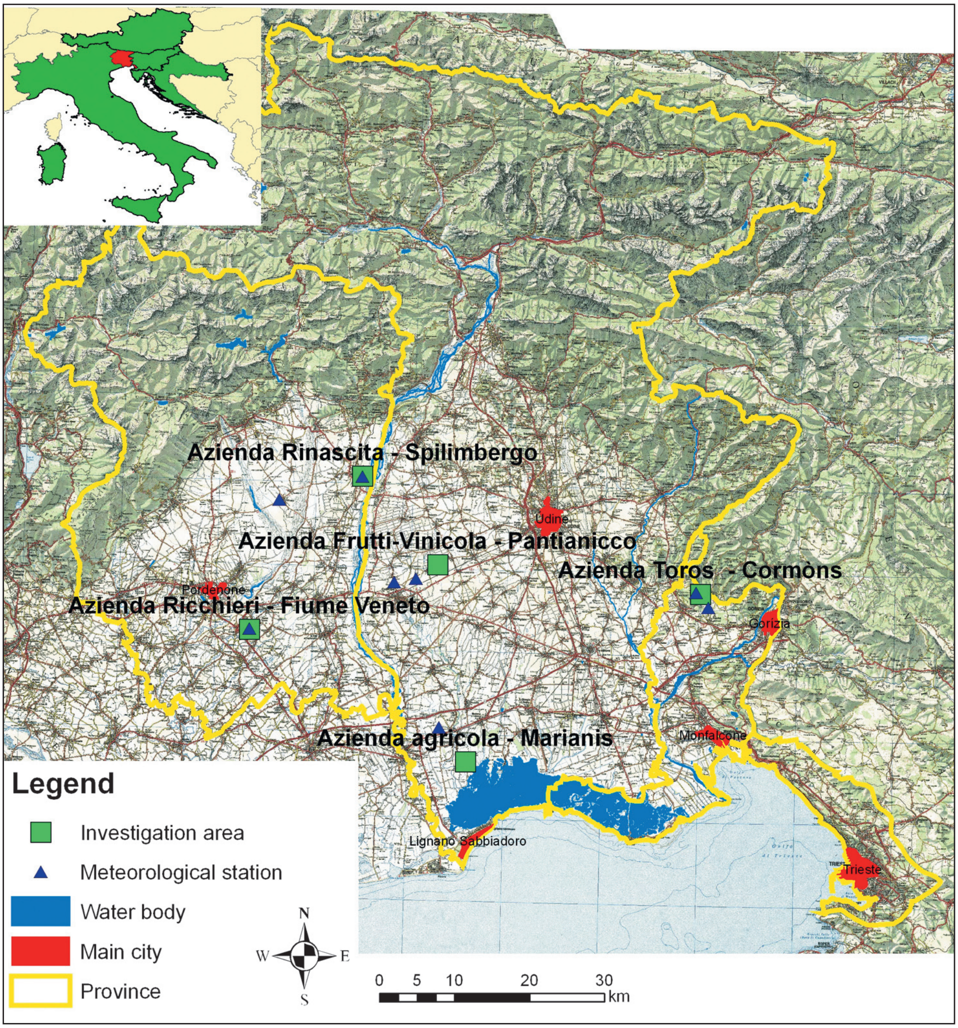

Fig. 1: Geographical location of the five areas investigated.
Geographische Lage der fünf Untersuchungsgebiete.

3. CropSyst simulation model

3.1. Model description

To achieve the project's targets the cropping systems simulation model CropSyst (V. 3.04.08) has been applied. The model's objective is to serve as an analytical tool to study the effects of cropping systems management on crop productivity and the environment. With this purpose, CropSyst simulates the soil water budget, the soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and irrigation.

These simulations are affected by weather, soil characteristics, crop characteristics, and cropping system management options, including crop rotation, cultivar selection, irrigation, nitrogen fertilization, pesticide applications, soil and irrigation water salinity, tillage operations and residue management. CropSyst is a suite of programs developed in the early 1990s, tested worldwide and designed to work cooperatively, that provides users with a set of tools to analyze the productivity and the environmental impact of crop rotations and cropping systems management at various temporal and spatial scales. The main components of the Crop-Syst Suite are: a CropSyst parameter editor, a cropping systems simulator (CropSyst model), a weather generator (ClimGen), a GIS-CropSyst simulation co-operator (ArcCS), a watershed analysis tool (CropSyst Watershed) and several utility programs (C. O. Stöckle et al., 2003). The water budget in the model accounts precipitation, irrigation, runoff, interception, water infiltration, water redistribution in the soil profile, deep percolation, crop transpiration and evaporation. Water redistribution in the soil can be simulated by a simple cascading approach or a numerical solution of the RICHARD's soil flow equation (G. S. Campbell, 1985). Boundary conditions allow for flux or saturated upper boundaries and for free drainage or saturated (water table) lower boundaries. CropSyst offers two options to calculate reference crop ET (ET_0): the PENMAN-MONTEITH model (J. Monteith, 1965) and the PRIESTLEY-TAYLOR model (C. H. B. Priestley & R. J. Taylor, 1972). The implementation of the PENMAN-MONTEITH model follows the methodology suggested by FAO (R. G. Allen et al., 1998). The management module includes automatic and scheduled management events. The automatic event manager (irrigation and nitrogen fertilization) continuously checks the soil water and nitrogen content and it can be programmed to provide management for maximum growth or to implement deficit prevention strategies. Events can be set to occur on specific dates, dates relative to the planting date, or synchronized to the phenologic development of the crop or to the occurrence of specified conditions (e.g. automatic irrigation). The CropSyst's outputs are organized into daily, harvest and yearly reports, daily nitrogen balance, growth nitrogen balance and annual nitrogen balance.

3.2. Data collection

Due to the complexity of simulating all physical and biological processes within the soil, crops and atmosphere, the model requires a very high number of real, theoretical and experimental data (Fig. 2). For this reason, the data collection for setting up the model was very time consuming. The most important input parameters that have been collected or directly measured in the fields are listed below, while the other required parameters are just estimated:

- **Meteorological daily data**: precipitation [mm], maximum temperature [°C], minimum temperature [°C], solar radiation [MJ/m^2], maximum relative humidity [%], minimum relative humidity [%] and wind speed [m/s].
- **Location of the meteorological station**: latitude.
- **Crop data**: maximum root depth; monthly values of the Leaf Area Index (LAI): measured using the LAI-2000 Plant Canopy Analyzer; phenology: emergence, peak LAI, beginning of flowering, beginning of grain filling and physiological maturity; yield. While the Green Area Index (GAI) defined as the ratio of leaf green area to the area of ground on which the crop is growing has been calculated by the model.
- **Management**: irrigation: date of irrigation [mm/dd] and quantity of water [mm]; fertilization: date of fertilization [mm/dd] and amount of nitrogen in form of nitrate

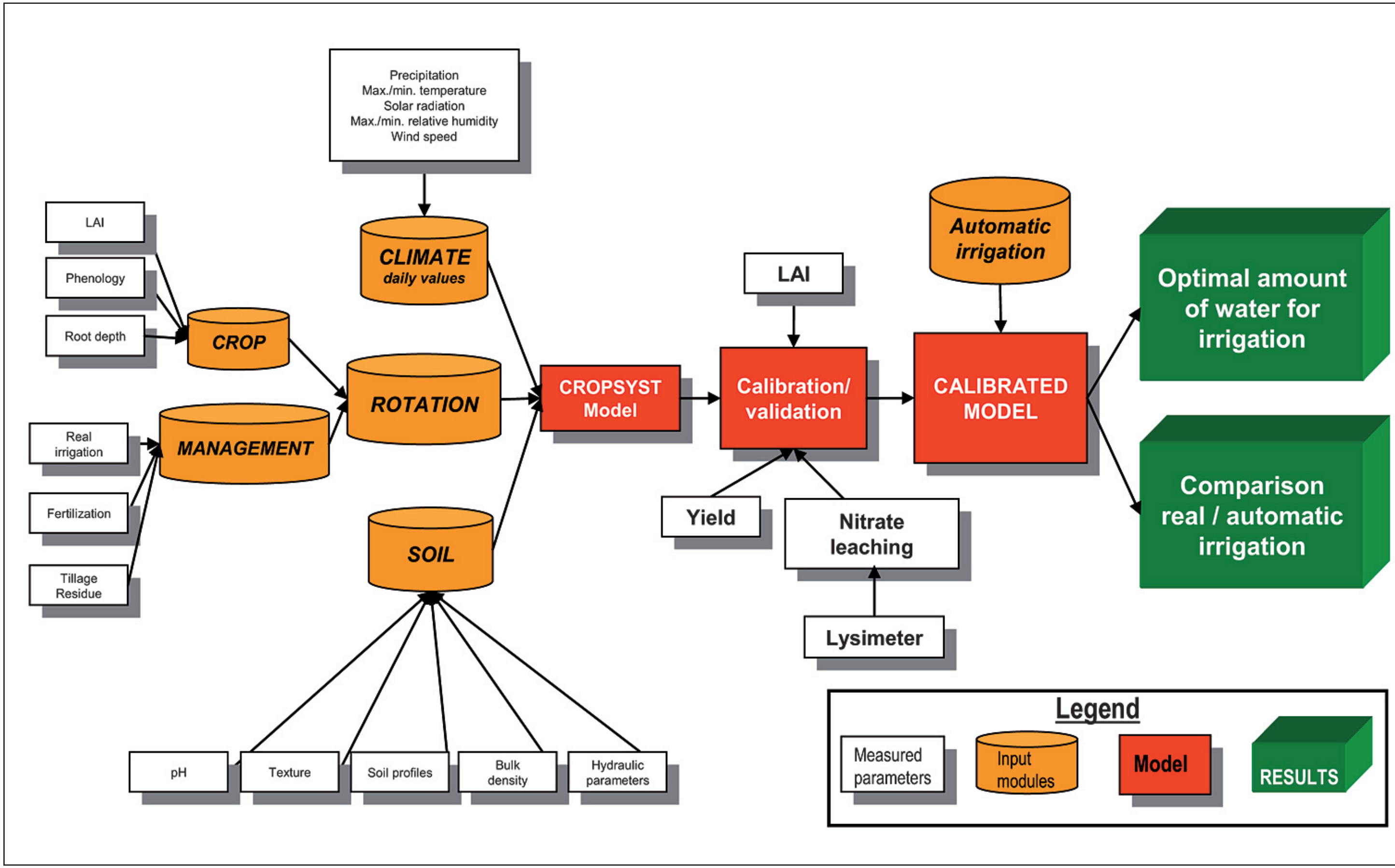

Fig. 2: CropSyst input data and processing schema. LAI – Leaf Area Index.
CropSyst-Inputdaten und Ablauf des Berechungsprozesses. LAI – Blattflächenindex.

or ammonium [kg/ha]; tillage operation: date of operation [mm/dd] and type of tillage; residue: date [mm/dd] and type; harvest: harvesting date.
– **Soil**: cation exchange capacity [meq/100g]; pH; texture: soil layer thickness [m], sand, clay and silt [%]; hydraulic properties: permanent wilting point [m^3/m^3], field capacity [m^3/m^3], bulk density [g/cm^3], saturated hydraulic conductibility [m/d].

An overview of the CropSyst input modules, measured data and processing schema are shown in fig. 2.

4. Irrigation water requirement analyses

4.1. Methodology and main processing steps

The methodology is the same for all five investigation areas, therefore only the processing steps of the ERSA experimental site "Rinascita" (Fig. 3) are described in detail since it is the most interesting and complete investigation area. In any case, the results of all five study areas are reported in chap. 5.

Applying CropSyst model two vegetative cycles for maize and vineyard are simulated. For the maize, two hybrids have been selected: 44 DEKALB for the year 2006 and Pioneer PR38H67 for the year 2007. For the vineyard, the Tocai variety has been taken.

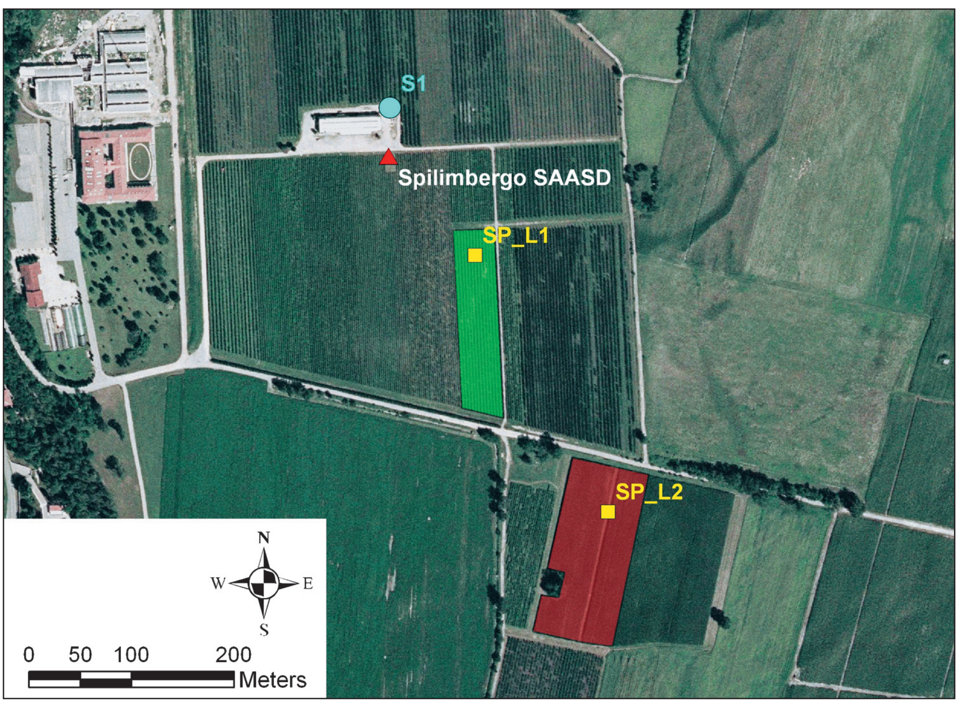

Fig. 3: Test site of ERSA experimental farm "Rinascita". Red: field of maize; green: vineyard; S1: irrigation well; SP_L1 and SP_L2: lysimeters; Spilimbergo SAASD: meteorological station. Untersuchungsgebiet ERSA Versuchsanlage „Rinascita". Rot: Maisfeld; grün: Weingarten; S1: Bewässerungsbrunnen; SP_L1 und SP_L2: Lysimeter; Spilimbergo SAASD: meteorologische Station.

The irrigation of the farm is from its own groundwater well with a depth of about 60 m. The irrigation systems adopted were the “overhead irrigation” for the maize and “Microjet” for the vineyard. As mentioned in chap. 2 the field of maize and the vineyard are also equipped with lysimeter stations.

The lysimeter stations SP_L1, SP_L2 and the irrigation well S1 (Fig. 3) have been sampled monthly to analyze the concentration changes of the main cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-) and the filed parameters like pH, electrical conductivity and water temperature. The isotopic composition of the stable isotopes ^2H and ^{18}O has also been determined at monthly interval.

Eighteen soil samples were obtained from the middle of March to the middle of November 2006 and 2007. Soils were sampled following a composite sampling approach, bulking four individual samples for each experimental field. When experimental lysimeters were present – like in Rinascita’s farm – individual samples were randomly located at a distance of 10–15 m from the lysimeter. Individual samples were collected in the 0–30 cm soil using a small spade in very gravelly soils like in the Rinascita’s farm. The characterization of the soils in terms of texture, pH and bulk density were measured to use as a main input for the CropSyst in its soil module. The other hydraulic soil parameters like field capacity, permanent wilting point and saturated hydraulic conductivity were calculated by the model itself. Additionally, other soil parameters like soil moisture, electrical conductivity, DTC (dissolved total carbon) and DTN (dissolved total nitrogen) were analyzed.

To follow the growing stages of the crops during the simulations, the crop phenology development was monitored and the LAI was directly measured in the field using the Plant Canopy Analyzer LAI-2000. The farm is also equipped with its own agro-meteorological station. For the year 2006, the meteorological data were collected directly from this station, however for the year 2007, due to some technical problems, the data were collected from another station located at Vivaro (about 10 km southwest of Azienda Rinascita, fig. 1), a part of the regional meteorological network (ARPA-FVG/OSMER).

4.2. Model set-up

At the end of every growing season, all the input data requested by CropSyst, such as meteorological data, irrigation management, fertilization management, crop rotation, crop phenology and soil parameters, were collected and implemented into the model. The cropping year 2006 has been calibrated and processed to be used as the initial condition for the second cropping year.

The selected crops have been calibrated by adjusting the values of the crop parameter module to bring the simulated yield to a closer value to the real yield measured after the harvest.

After the model calibration, the amount of water used for irrigation has been compared to the automatic irrigation amount calculated by the model. This value yields the optimal amount of water to be applied to the irrigation scheme to satisfy the crop water need.

4.3. Model results – maize

This chapter describes the results of the test site ERSA experimental farm “Rinascita” for maize in the cropping season 2007 (sowing 06. 04., harvesting 05. 09., fig. 4–9).

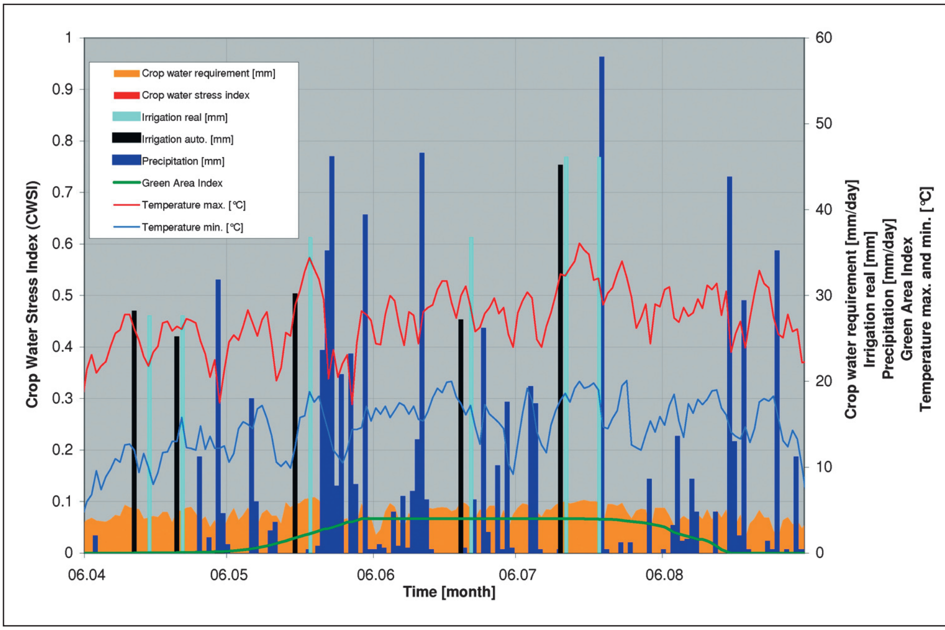

Fig. 4: Cropping season 2007 of maize from sowing to harvesting applying real and automatic irrigation.
Wachstumsperiode Mais 2007 mit traditioneller und automatischer Bewässerungspraxis.

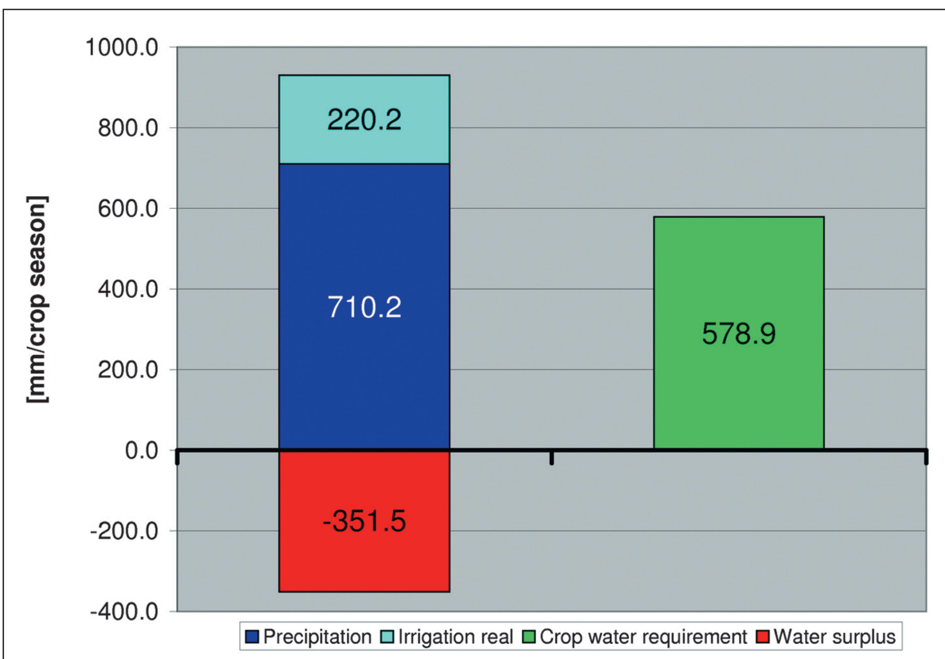

Fig. 5: Crop water requirements of maize during the cropping season 2007.
Wasserbedarf von Mais in der Wachstumsperiode 2007.

Figure 4 shows the simulation results applying real and automatic irrigation. In this case, no crop stress was observed. This is an indication that enough water has been used for irrigation to completely satisfy the crop water need, but it does not indicate if the optimal amount of water requested by the crop has been met. Analyzing and comparing the real and automatic irrigation is possible to determine how and when the model has applied the most appropriate amount of water needed by the crop.

Figure 5 shows the comparison between the CWR and both precipitation and real irrigation. The CWR is the real water need requested by the selected crop under the climatic conditions of the cropping year. The water surplus, in this case, is the difference between the CWR and the sum of precipitation and real irrigation. Due to the high variability of the precipitation during the year 2007, both in terms of quantity and spatial distribution was necessary to irrigate even though the precipitation during the cropping period was higher than the CWR.

Figure 6 shows the measured yield and simulated yields respectively using both real and automatic irrigation. The comparison between measured and simulated yield has been adopted as the method for the model calibration. Therefore, the closer the simulated yield was to the measured one, the higher the accuracy of the model was. The final model calibration reached an accuracy degree of 99.2 %, which in this case is equivalent of 9079.1 kg/ha for both simulated yields (real and automatic irrigation) instead of 9150.0 kg/ha of the measured yield.

In addition, the development curve of the ground biomass and the crop productivity did not show any differences between real and automatic irrigation.

The difference between real and automatic irrigation in terms of total amount of water used during the cropping season is shown in fig. 7. In this case, there was an over irrigation of 65.2 mm.

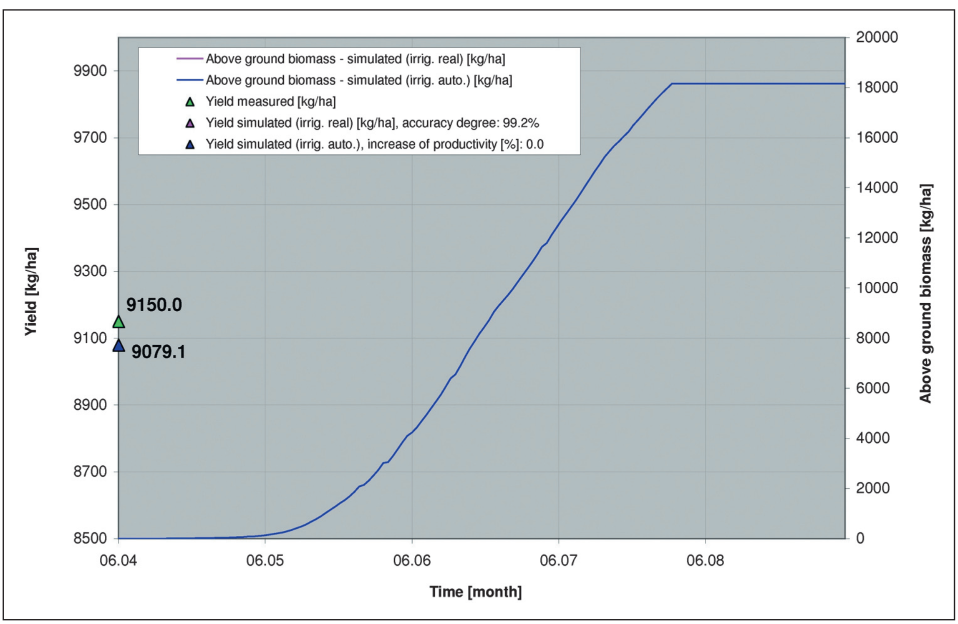

Fig. 6: Yield and above ground biomass of maize during the cropping season 2007.
Ertrag und Biomasse von Mais an der Oberfläche in der Wachstumsperiode 2007.

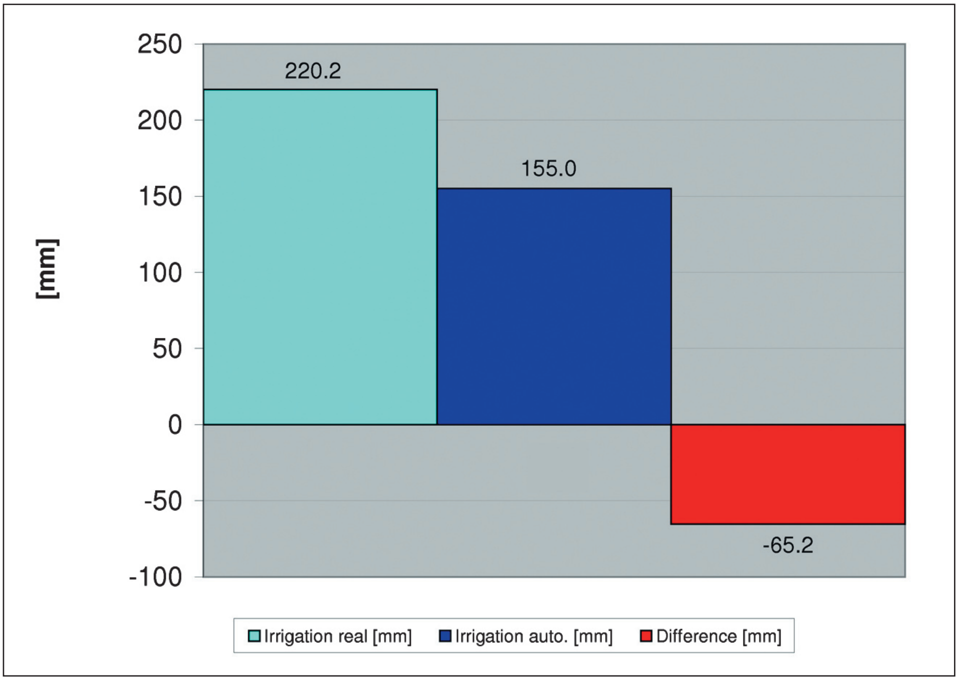

Fig. 7: Difference between real and automatic irrigation during the cropping season 2007.
Differenz zwischen traditioneller und automatischer Bewässerungsmethode in der Wachstumsperiode 2007.

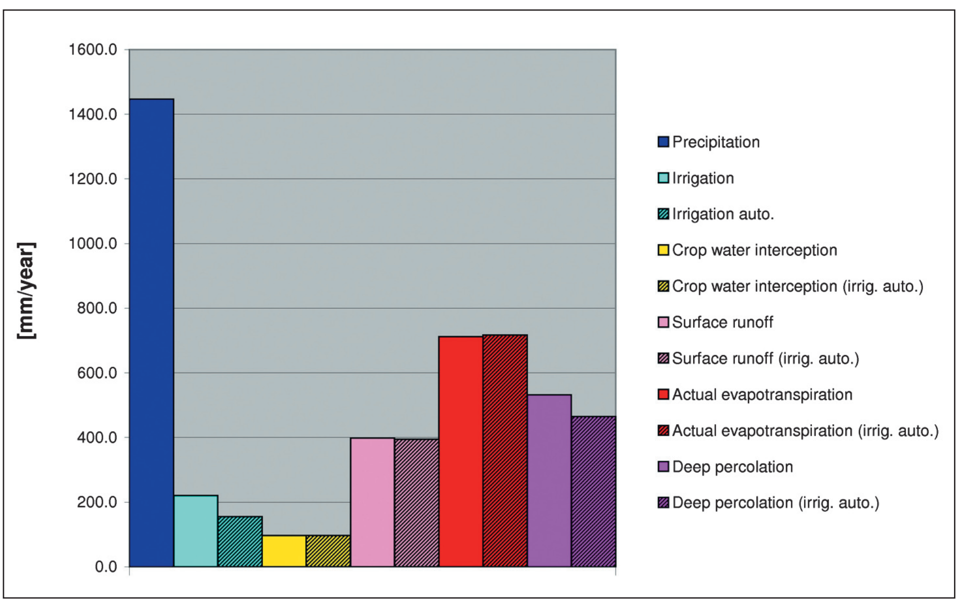

Fig. 8: Annual water balance components for maize calculated for the year 2007.
Jährliche Wasserbilanzkomponenten für Mais berechnet für das Jahr 2007.

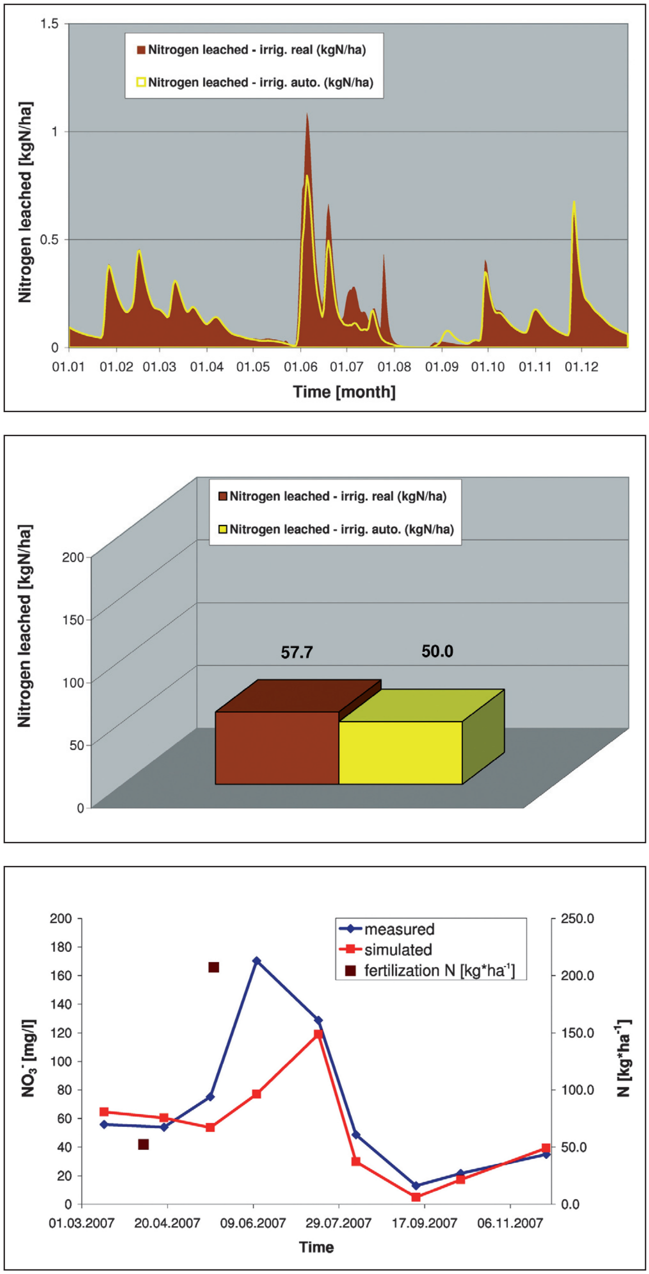

Fig. 9: Daily nitrogen leached (top) and accumulated nitrogen leached (centre) with real and automatic irrigation for the year 2007; comparison between measured and simulated nitrate concentration vs. time (bottom; mean NO_3^- from lysimeter: suction cups left and right at 86 cm depth).
Tägliche Stickstoffauswaschung (oben) und kumulierte Stickstoffauswaschung (Mitte) mit traditioneller und automatischer Bewässerungsmethode für das Jahr 2007; Vergleich zwischen berechneter und simulierter Nitratkonzentration vs. Zeit (unten; Mittel NO_3^- von Lysimeter: Saugkerzen links und rechts in 86 cm Tiefe).

The effects of the irrigation on the water balance are shown in fig. 8. Here it is possible to see the differences between real and automatic irrigation for each water balance component. An important component of the water balance considered in CropSyst is the deep percolation as the water that moves down through the soil profile below the root zone. This amount of water cannot be utilized by the plants anymore and is thus available for the groundwater recharge.

For this reason, it is important to apply the optimal amount of water to the irrigation plant, not only as a good practice for saving water, but also to reduce the groundwater contamination coming from agricultural activities. An example of this is shown in fig. 9, where the daily nitrogen leaching between real and automatic irrigation are compared.

To verify the model accuracy, the simulated and measured nitrate concentration from the lysimeter SP_L2 are compared (Fig. 9 bottom).

5. Results

After two years of crop simulations all the results of the five areas investigated have been collected, processed and compared.

Table 1 shows the results between the real amount of water used for the irrigation and the automatic irrigation during the cropping season 2006 and 2007 as simulated by

Tab. 1: Comparison between real and automatic irrigation of the five investigation sites.
Vergleich zwischen traditioneller und automatischer Bewässerungsmethode in den fünf Untersuchungsgebieten.

Crop/year	Real irrigation [mm]	Automatic irrigation [mm]	Difference [mm]	Sum of the difference per farm [mm]
Rinascita				
Maize 2006	245.1	235.2	9.9	**174.6**
Maize 2007	220.2	155.0	65.2	
Vineyard 2006	212.0	140.0	72.0	
Vineyard 2007	27.5	0	27.5	
Marianis				
Maize 2006	130.0	125.0	5.0	**–15.0**
Maize 2007	125.0	120.0	5.0	
Soybean 2007	100.0	125.0	–25.0	
Ricchieri				
Maize 2006	196.0	245.0	–49.0	**–54.0**
Maize 2007	85.0	90.0	– 5.0	
Toros				
Vineyard 2006	0	0	0	**0**
Vineyard 2007	0	0	0	
Pantianicco				
Vineyard 2006	144.0	150.0	– 6.0	**123.0**
Vineyard 2007	129.0	0	129.0	
TOTAL	**1613.8**	**1385.2**	**228.6**	

the model. The irrigation differences have shown very clearly that it is not easy to meet the optimal crop water requirements. Furthermore, these results indirectly give an idea of the irrigation management efficiency of the farms.

At Rinascita farm in Spilimbergo, mainly due to the soil characteristics (very gravelly soils), the irrigation management is more difficult in comparison to the other farms, and thus, this farm shows the highest wastage of water for irrigation (174.6 mm). To get a better understanding of the irrigation management of the farms, it is necessary to compare the irrigation differences with the Crop Water Stress Index (CWSI), which is another output of the model. The CWSI is defined as one minus the ratio between the actual transpiration (AT) and the potential transpiration (PT) achieved during the crop growing cycle: $[1-(AT/PT)]$.

This value is used as an indicator of the plant's response to environmental conditions. The range of the values is from 0 to 1 where 0 is no stress and 1 is maximum stress. Under very limited water conditions or high crop water demand, the deficit can be so severe as to cause crop failure as thus the ratio becomes close to 1.

An overview of the irrigation differences and the CWSI expressed as seasonal sum of the daily values is shown in fig. 10.

From fig. 10 it is possible to understand, that the simulated crops at the Rinascita farm in Spilimbergo did not show any water stress (see also fig. 4) due to over-irrigation.

On the other hand, the 2007 soybean crop of Marianis's farm showed a high CWSI caused by an irrigation deficit. In this particular case, the irrigation deficit has been affected by a technical problem experienced on the irrigation plant of the farm during an important growing stage of the crop. Concerning the 2006 and 2007 maize crop the irrigation has been managed in nearly the optimal way.

In Fiume Veneto, the Ricchieri's farm management did not show problems even when there was a modest irrigation deficit that caused some crop water stress.

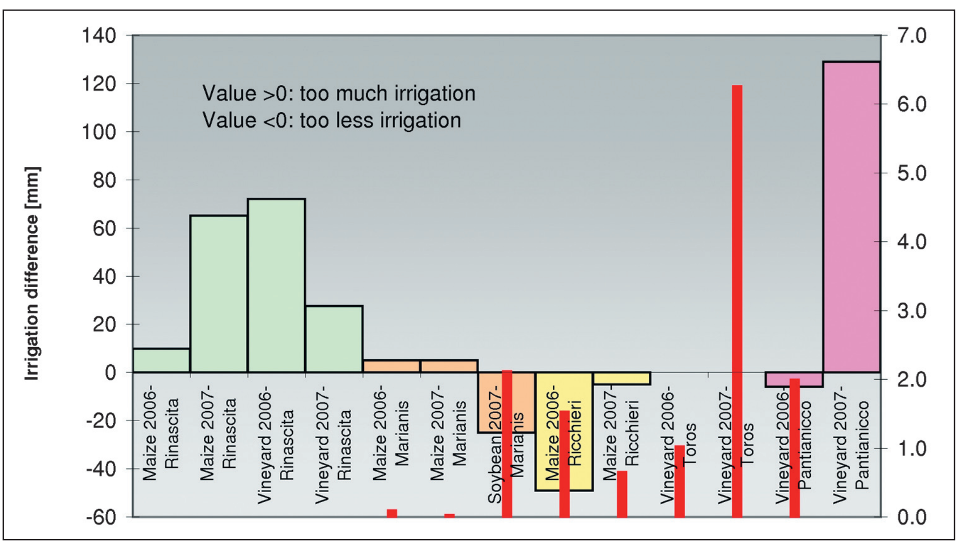

Fig. 10: Overview of the irrigation differences in all five investigation sites for the years 2006 and 2007. Red: Crop Water Stress Index (CWSI).
Übersicht über die Bewässerungsmengendifferenzen in den fünf Untersuchungsgebieten für die Jahre 2006 und 2007. Rot: Wasserstressindex der Pflanzen (CWSI).

The private farm of the Toros's family produces high quality wines. Usually in this area the irrigation practices are not necessary for producing high quality wines. The crop water stress simulated in the model was not a real problem for the wine production itself because it happened in the late development phase of the grapes where it is better to have a dry period to ensure a high wine quality, hence there was no real need to irrigate.

In Pantianicco, where the farm does not produce high quality wine, there were some problems in 2007 due to the over-irrigation.

Summary

The study areas are situated in the Friulian Plain (Pianura Friulana) of the Region Friuli-Venezia Giulia in Italy, which is characterized by intensive agricultural activities with a usable agricultural area of 218,812 ha, 145,400 ha (66.45 %) of which are irrigated.

The main objective of the research study carried out in the framework of "Competence Network Water Resources and their Management" (Knet Water) was to develop a methodology for the optimization of the water resources for irrigation, by taking into account the effective crop water requirements of maize, soybean (year 2007 only) and grapevine for the cropping season 2006 and 2007. The investigation has been applied to five farms with different pedoclimatic characteristics, but all representative of the Friulian Plain.

The crop water requirement is the amount of water required by the cropped fields to compensate the evapotranspiration losses. To achieve the goals of the project, the cropping systems simulation model CropSyst was used.

Beside the estimation of the crop water requirements for the selected crops, the difference between the effective amount of water utilized during the traditional irrigation practices and the optimal amount of water that should be used for the irrigation scheme to satisfy the crop water needs during the growing seasons has also been calculated.

In this Knet project, the cropping and irrigation management of two vegetative cycles in four experimental and demonstrative farms showed an irrigation surplus of roughly 228.6 mm.

In the frame of "Knet-Phasing out", the same methodology will be adapted and applied, this time, to four private farms situated in the vicinity of the four ERSA's farms having similar pedoclimate characteristics. At the end of this on-going project, the irrigation management between experimental and private farms of the Region Friuli-Venezia Giulia will be compared.

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Zusammenfassung

Das Untersuchungsgebiet liegt in der Friulanischen Ebene der italienischen Region Friaul-Julisch Venetien. Der intensiv landwirtschaftlich genutzte Teil des Gebietes umfasst eine Gesamtfläche von 218.812 ha, von der 145.400 ha (66,45 %) künstlich bewässert werden.

Ziel der im Rahmen des „Kompetenznetzwerkes Wasserressourcen und deren Bewirtschaftung" (Knet Wasser) durchgeführten Studie war die Erarbeitung eines modernen Konzeptes für die Optimierung der bestehenden Bewässerungspraxis durch gezielte Anpassung des Bewässerungsregimes an den individuellen Wasserbedarf bedeutender landwirtschaftlicher Kulturen wie Mais, Soja und Wein in fünf regionaltypischen landwirtschaftlichen Testgebieten mit unterschiedlichen klimatischen und pedologischen Bedingungen.

Die Berechnungen des Wasserbedarfs der verschiedenen Kulturen auf den einzelnen Standorten erfolgten mit Hilfe des biophysikalischen Pflanzenwachstumsmodells CropSyst (Cropping Systems Simulation Model). Das Modell berechnet unter Berücksichtigung zahlreicher lokaler und pflanzenspezifischer Parameter eine optimale Bewässerungsstrategie. Die mit Hilfe des Modells erhaltenen Bewässerungsszenarien wurden anschließend der tatsächlichen lokalen Bewässerungspraxis in den Jahren 2006 und 2007 gegenübergestellt und individuell bewertet.

Die im Zuge des „Knet-Projekts" durchgeführten Untersuchungen zeigten, dass die herkömmliche Bewässerung im betrachteten Zeitraum von zwei Vegetationsperioden im Vergleich zur optimalen Variante einen Bewässerungsüberschuss von insgesamt 228,6 mm hat.

Die erarbeitete Methodik für die Optimierung regionaler Bewässerungsstrategien wird derzeit in einem Folgeprojekt im Rahmen des „Knet Phasing out" bei vier privaten landwirtschaftlichen Betrieben der Region Friaul-Julisch Venetien angewendet und mit den Ergebnissen der staatlichen Versuchsbetriebe verglichen.

Keywords: Friulian Plain, irrigation management, CropSyst, lysimeter, nitrate

Schlüsselwörter: Friulanische Ebene, Bewässerungsmanagement, CropSyst, Lysimeter, Nitrat