VINEYARD FULL IRRIGATION REQUIREMENTS UNDER CLIMATE CHANGE SCENARIOS FOR EBRO VALLEY-SPAIN.

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Summary

The possible effect of climate change during the forthcoming 20 years on full irrigation vineyard requirements was simulated by combining global circulation models and crop models. 2010-2030 climate change scenarios were obtained from the CGCM2 model outputs provided by the Canadian Center for Climate Modeling and Analysis according to the IPCC SRES A2 scenario for greenhouse gases emissions. A historical 42 year series of weather data from Lleida (north east corner of the Iberian Peninsula) was used in combination with the LARS-WG weather generator to generate 100 realizations of local weather data corresponding to 2010, 2015, 2020 and 2025. Climate change scenarios were produced by perturbing the weather generator according to the CGCM2 results corresponding to the study site. CropSyst was used to simulate vineyard water balance. Crop water requirements were simulated from an automatic calculation implemented in the model which derived the amount of applied water that would maintain soil at field capacity while minimizing drainage according to a daily routine calculation. Data from a vineyard irrigation experiment which considers fully irrigated and deficit irrigated vines were used to adjust the crop model parameters. For the adjustment it was considered vineyard water requirements from FAO-56 method, field measures on soil texture and apparent density, crop growth and plant water stress development, as well as vine rooting depth. Further adjustments were done to simulate soil evaporation from a drip irrigation system. For the model validation, simulations on berry yield were compared to experimental data for both irrigation treatments but across three different soil types differing in soil depth (from 0.5 to 0.9 m.). A reasonable yield prediction was found according to a Willmot concordance index of 0.95. The weather generated indicated an increase in average air temperature of 1.5ºC from 2005 to 2025 period. Annual Evapotranspiration increased by a maximum 43 mm and rainfall decreased around 100 mm for the same period. Irrigation requirements had increased by 50 mm from 2005 to 2015. Crop development (bud-break and harvest) was advanced by two weeks due to increased temperatures. Crop coefficients simulated by CropSyst mimicked well those used by FAO-56 during 2005. However, the 2025 scenario suggested substantial increases in crop coefficients early spring, and also earlier decreases because of the advancement in the time of harvest. It is therefore concluded that the most important impact of climate change would be more on the irrigation scheduling adjustments to variations in crop development than on possible annual increases in crop water demand.

Introduction

During the last decades there have been a large number of published studies describing how plants can respond to short tem air elevated CO_2. This bountiful literature has served to parameterized plant responses, and it has recently been implemented in various crop models so that the effects of climate change can be simulated by computer. However there is little information on how irrigation districts will have to handle these changes and most managers and policy makers are still thinking if this will be needed at all. However, it looks rather straight forward that with the rising temperatures, evapotranspiration will have to increase, and that possible changes in rainfall during the crop growing season will have the last word on what has to come. AGRIDEMA project was born from the complexity of possible outcomes with global weather changes and with the idea to provide some sort of assessment by using the available mathematical tools that could form a partnership between climate and crop models. The use of the two types of model combination is used for the prediction of the impacts of climate change on irrigation management in the Mediterranean region. This pilot project studies the particular case of irrigated vineyards in the northern east corner of the Iberian Peninsula (Ebro basin).

Materials and Methods

Future Climate Scenarios

The 2010-2030 Climate Change scenarios were taken from the CGCM2 model outputs, provided by the Canadian Centre for Climate Modelling and Analysis (Flato et al., 2000; Flato and Boer, 2001). The IPCC SRES A2 scenario for greenhouse gases emissions (IPCC, 2001) was considered.

The CGCM2 model was preferred to others available, because it provides free internet access to daily simulation data in a text format. Hence, this model is more suitable for simple agricultural applications anywhere. According to Merrit et al (2006), results considering CGCM2 are similar than those obtained through other general circulation models.

A historical meteorological series of Lleida (INM, Spanish Insituto Nacional de Meteorología), Spain (41.38 N, 0.35 E), comprising daily data from 1956 to 1998 of maximum and minimum temperatures, sunshine hours and precipitation; was used in combination with the LARS-WG weather generator (Semenov and Barrow, 2002) to generate 100 realizations of local weather corresponding to 2010, 2015 and 2025. A weather generator produces synthetic daily time series of climatic variables statistically equivalent to the recorded historical series, as well as daily site-specific climate scenarios that could be based on regional GCM results (Semenov and Jamieson, 2001). Different weather generators are available, but according to Wilby and Wigley (2001), the US-made and the UK-made WGEN and LARS-WG are the most widely used. Besides, LARS-WG results are as accurate as those obtained with WGEN and other weather generators (Mavromatis and Jones, 1998; Semenov et al., 1998; Mavromatis and Hansen, 2001).

The climate change scenarios were obtained perturbing the weather generator according to the CGCM2 results corresponding to the study site, i.e., Northeast of Iberian Peninsula. The relative change in wet and dry series lengths, as affected by global change, was done following the approach recommended by Semenov and Barrow (2002), based on the daily CGCM2 outputs for each ten-year range. The relative changes in temperature standard deviations, as well as relative changes in mean temperature, precipitation amount and solar radiation were obtained from the CGCM2 daily estimations, as suggested by Semenov and Barrow (2002).

The weather data generated required further normalization in order to be used for irrigation purposes. Data from conventional weather stations such as those of the INM are not suitable for the calculation of the evapotranspiration model most widespread and accurate for farming irrigation scheduling (Penman-Monteith model, ET-PM). To calculate ET-PM, weather stations must accomplish with specific requirements on site location and grass cover conditions (agro-meteorological stations). Typically, evapotranspiration estimates from agro-meteorological stations are substantially lower from those obtained by conventional stations and other ET models. Unfortunately, agro-meteorological stations began to be used in Spain after the decade of the eighties, and thus their data series is not long enough to be used for generating climate scenarios. The required normalization was done by linearly relating temperature data from a ten year series (1990-2000) between the INM weather station and the agro-meteorological station that was located in the same experimental fields where the experimental data was gathered for the simulations.

The Crop Model

The simulation model CropSyst (Stockle and Nelson, 1998) in its recently released version (4.04.14) permits to simulate crop water balance in vineyards on a single season basis and with a daily calculation routine. Outcomes of crop water use starts from bud break and finalize at harvest. Estimates of crop water consumption before and after this period were yearly completed by the FAO-56 method (Allen et al., 1998). CropSyst simulates soil water balance, crop phenology, vine water uptake, canopy intercepted, leaf development, reproductive growth and final harvest. The model considers several management options for irrigation, including the automatic calculation of applied water so that soil is maintained at field capacity while minimizing drainage. The latter option was adopted for the genuine CropSyst determination of vineyard irrigation requirements under future climate scenarios. This evaluation was also compared to a real case in which the FAO-56 was used. Elevated atmospheric CO_2 effects on growth and crop water use were simulated by using CO_2 sub model built in CropSyst and compared to a non CO_2 increased scenario, since long term crop responses to elevated CO_2 are not fully tested. The predicted CO_2 atmospheric concentration values were as in other reports, i.e, 554 ppm at 2050 with a baseline of 334 ppm at 1960 (Richter and Semenov, 2005). CO_2 concentration at any considered data were inferred from the latter interval, ie., 443, 430, 418, 406 ppm, for 2010, 2015, 2015 and 2025, respectively.

Experimental data

For parameterization and validation of the model, data from an irrigation experimental field were gathered during 2003. In a 10 year old ‘Tempranillo’ (*Vitis vinifera* L.) vineyard from Raïmat winery (Lleida, Spain) two different irrigation treatments were established. The treatments consisted in: 1) Control fully irrigated treatment and 2) SSDI (seasonal sustained deficit irrigation) in which vines were irrigated at 50% of Control vines. Treatments were replicated 4 times in soils differing in soil depth. Replications were arranged according to an experimental design with 4 completely randomized blocks. Each block-replication consisted of two rows of 12 vines surrounded by two more rows equally irrigated that functioned as a vine guards. Full irrigation requirements were determined according to FAO-56 methodology.

At the end of the experiment, soil water holding capacities were determined by opening trenches at every site and pressure release curves were determined for every horizon according to Richter technique (in a Richard membrane). It was then observed that the irrigation treatments affected root distribution with depth, SSDI vines having more superficial root distribution than Control vines.

Vine intercepted radiation was determined at peculiar days by measuring with a AccuPAR Ceptometer (Decagon Devices Inc., Pullman, WA, USA).

Vine water status was weekly evaluated by measuring midday stem water potential with a pressure chamber (Model 3005; Soil Moisture Equipment, Santa Barbara, CA, USA.) according to Shackel et al (1997) methodology.

At harvest (second week of September) grape production was manually harvested per each vine individually. Percentage dry matter was calculated by drying 1 kg of grapes per replication in an oven at 70ºC. This was used to convert yield fresh grape mass to yield dry mass.

Model parameterization

Soil hydraulic properties required to run the CropSyst were estimated from field measurements of soil texture and apparent soil density. For this purpose, the equations provided by Saxton et al. (1986) which are implemented in CropSyst were used (Table 1). As regard to irrigation types, the model only considers flooding irrigation. Therefore the model assumes all applied water is spread throughout the entire planting space. Then, simulated soil evaporation results in substantially higher estimates than what would occur in using sprinkler irrigation systems. To correct this effect, a top soil layer of 0.005 m thickness was added so that soil evaporation was reduced to a 1/3 of crop evapotranspiration (Girona et al,. 2002). Cascade method for soil water transport was preferred to finite differences method since the cascade calculations in the specific case of this study provided estimates better correlated to seasonal stress development under deficit irrigation conditions.

Irrigation treatments also required crop parameterization since field observations indicated that 50% deficit irrigation SSDI produced the majority of roots at the first soil top 0.25 m, whereas those of the Control were down to 0.4 m (we called this depth, observed rooting depth). This should be implemented by adjusting curvature root density distribution. Unfortunately this feature was not fully operative in the version 4.04.12. Irrigation treatment effects on rooting depth were then accounted by modifying maximum rooting depth parameter. Maximum rooting depth was calculated by adding half the distance between effective soil depth and observed rooting depth to the observed rooting depth. For the model parameterization Penman-Monteith reference evapotranspiration (ET-PM) was used (Allen et al., 1998). ET-PM was calculated from an automated weather station which had all sensors and requirements for the calculation of ET-PM. The station belongs to the Catalan network of agro-meteorological stations (XAC) and is located 400 m from the experimental site.

Since climate scenarios did not provide forecasts on humidity nor wind speed, simulations for the climate scenarios were performed using Priestley-Taylor (ET-PT). The CropSyst values for the aridity factor and Priestley-Taylor constant were the default values. These represented adequately ET-PM values for the experimental site. Crop phenology was adjusted by supplying degree days for each crop developmental phase as it occurred during 2003 season. Crop parameters for grape vines were adjusted by comparing yield simulations outputs simultaneously for SSDI and Control treatments with experimental data corresponding to the deepest block –replication conditions (> 1 m deep) (Table 2).

Table 1. Soil characteristics used in the simulations (20-35 cm).

Soil parameter	Control				SSDI			
Replication-Blok	R-1	R-2	R-3	R-4	R-1	R-2	R-3	R-4
Effective soil depth (m)	1.5	0.85	0.7	0.55	1.0	0.9	0.6	0.5
Apparent density (Mg/m2)	1.39	1.37	1.41	1.39	1.40	1.43	1.37	1.38
Field capacity (m3/m3)	0.283	0.284	0.286	0.286	0.280	0.286	0.280	0.283
Permanent wilt point (m3/m3)	0.113	0.135	0.106	0.112	0.115	0.106	0.133	0.135

Average soil texture was silty-loam

Table 2. Crop parameters used in the simulations.

Parameter	Value
Measured or field estimated	
Specific leaf area	12.00
Stem/leaf partition coefficient	2.00
Extinction coefficient for solar radiation	0.35
Begin flowering	352
Begin initial fruit growth	723
Begin rapid fruit growth	1627
Physiological maturity	2407
Fraction of total solids	0.30
Thermal time to bud break	500
Leaf water potential at the onset of stomatal closure	-700
Wilting leaf water potential	-1600
Manual CropSyst	
Unstressed light above ground biomass	0.003
Root length per unit root mass	90
Surface root density	4
Curvature of root density distribution	1.2
ET crop coefficient at full canopy	0.8
Adjusted to experimental data	
Actual to potential transpiration ratio that limits leaf area growth	0.85
Actual to potential transpiration ratio that limits root growth	0.5
Above ground biomass transpiration coefficient	8
Maximum fruit load	26250
Fraction of above biomass apportioned to fruit after flowering	0.9
Fraction of biomass apportioned to fruit during accelerated fruit growth	1
Translocation yield factor	0.1
Leaf duration	5000

Model validation

For the model validation, berry yield were compared to experimental data from different soil types and irrigation treatments. This was preferred to compare experimental data from different years under fully irrigated conditions because the former provided more of a clear signal at a field level. Seasonal trends on soil water content were also compared to midday stem water potential for congruence in water stress development. Although the latter parameters do not have to evolve exactly in the same way, some sort of agreement is expected. Simulations from the parameterized model were compared to 2003 yield experimental data which corresponded to the other 3 shallower sites that were not used for model parameterization (soil depths spanning from 0.9 to 0.5 m depth). Data from both treatments were considered, Control and SSDI.

For the model capacity forecast, the Concordance Index as proposed by Willmot (1982) was used.

Results and Discussion

The validation procedure revealed an index of concordance of Willmot d=0.95, what indicates a reasonable yield prediction from changes in irrigation and soil depth (Figure 1).

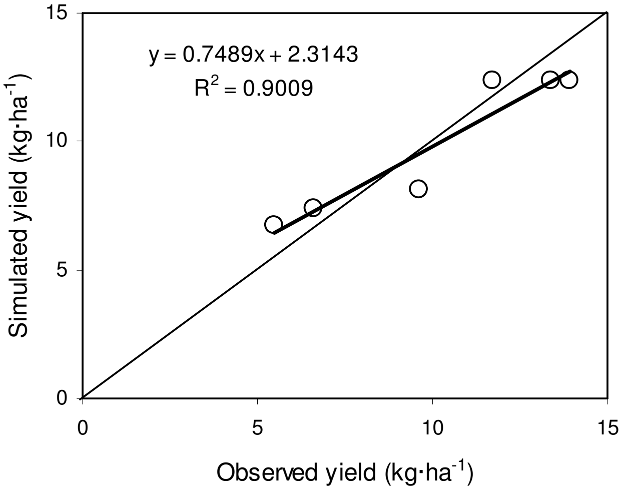

Figure 1. Yield relationship between observed values, and simulated estimates from CropSyst. Different observations corresponded to different irrigation treatments across different soil depths. Willmot concordance index was 0.95.

The outputs of CGCM2 model for the northeast Spanish quadrant are summarized in Figure 2 which predicts an increase in average annual temperature up to 4ºC by the end of the 21th century. Climate scenarios for the period object of study downscaled for Lleida and normalized for the agro-meteorological station used in this study predicted a progressive increase in annual average temperature from 2005 until 2020 of a maximum of 1.5 ºC (Figure 3A). The level off in temperature for 2025 might not imply a significant change in the pattern as it was only related to the natural year-to-year variability within a longer term framework of steady increasing in air temperature (Figure 2 and Figure 3A). Reference Evapotranspiration (ET-Hargraves model calibrated for the ET-Penman Monteith) compared to 2005 increased up to an annual maximum of 43 mm in 2020, which represents only a 4% increase from 2005 (Figure 3B). Annual precipitation seemed to decrease from the 1995-2005 average value of 395 mm to as little as 290 mm at the end of the considered period (2025). Global radiation values seemed to remained steady around the 15.3 MJ/m^{-2} throughout the simulated period (Figure 3B).

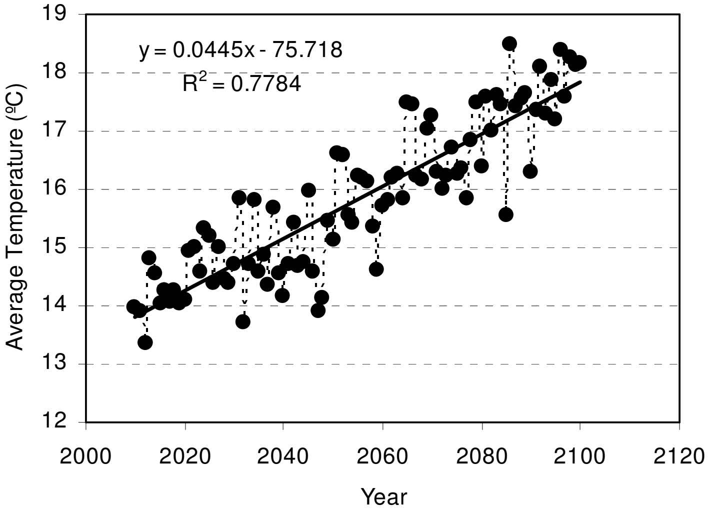

Figure 2. Average air temperature forecast as predicted by CGCM2 model from the Canadian Centre for Climate Modelling and Analysis corresponding to the Northeast quadrant of the Iberian Peninsula.

The predicted increase in temperature had a dramatic effect on the simulated time of bud break and harvest. Both, bud break and harvest, were advanced by about 2 weeks by 2025, whereas the period spanned between this two events were reduced by only 3 days (Figure 4). Crop water use increased slightly from 2005 initial values to any of the years contemplated in the future scenario, though increases accounted by no more than annual 30 mm (Figure 5A). The effect of no considering CO_2 increases on plant physiological feedbacks only represented a tiny decrease of 8 mm on annual crop water use (Figure 5A). Irrigation requirements, revealed a maximum increase in annual water demand of 50 mm (2005 vs. 2015). Irrigation requirements resulted more variable than crop water use because the latter includes both crop water use and effective rainfall, and rainfall was a lot more variable than any other weather parameter (Figure 5B). For instance, the lower requirements for 2020 accounted for more rainfall occurring during the crop developmental season than in any other of the years.

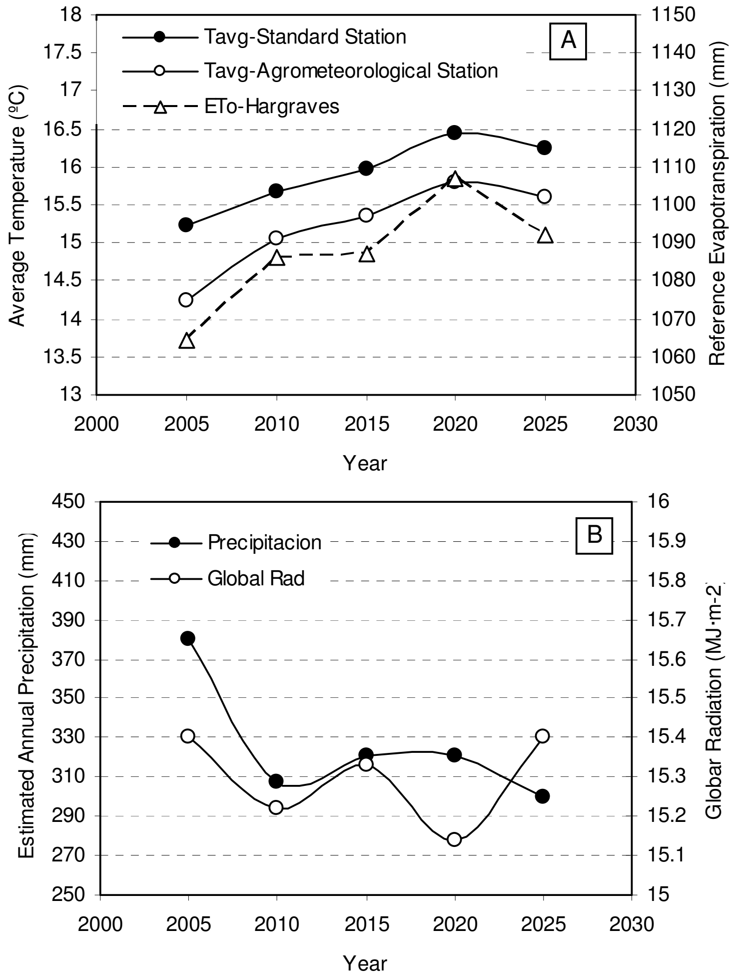

Figure 3. Yearly patterns of weather parameters (average temperature standard weather station and average temperature for agro-meteorological weather station) (A) and rainfall and evapotranspiration (B).

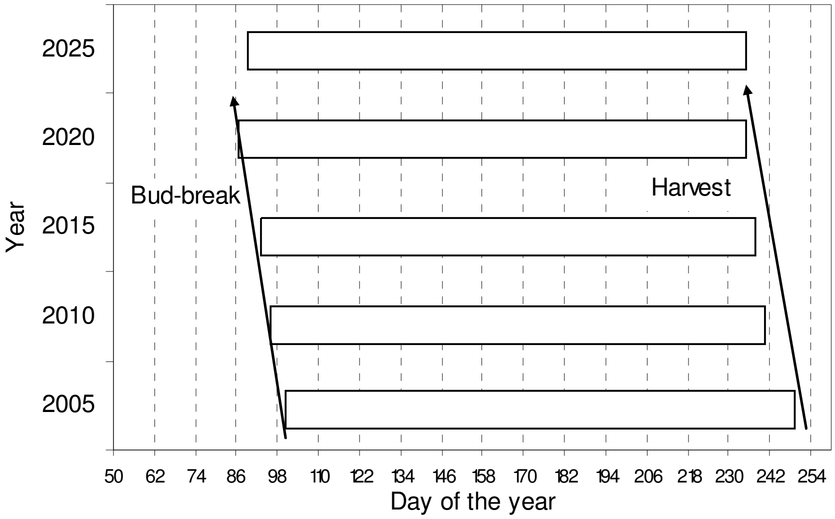

Figure 4. Evolution in crop development events (bud-break and harvest) throughout the considered climate change scenario (2010-2025).

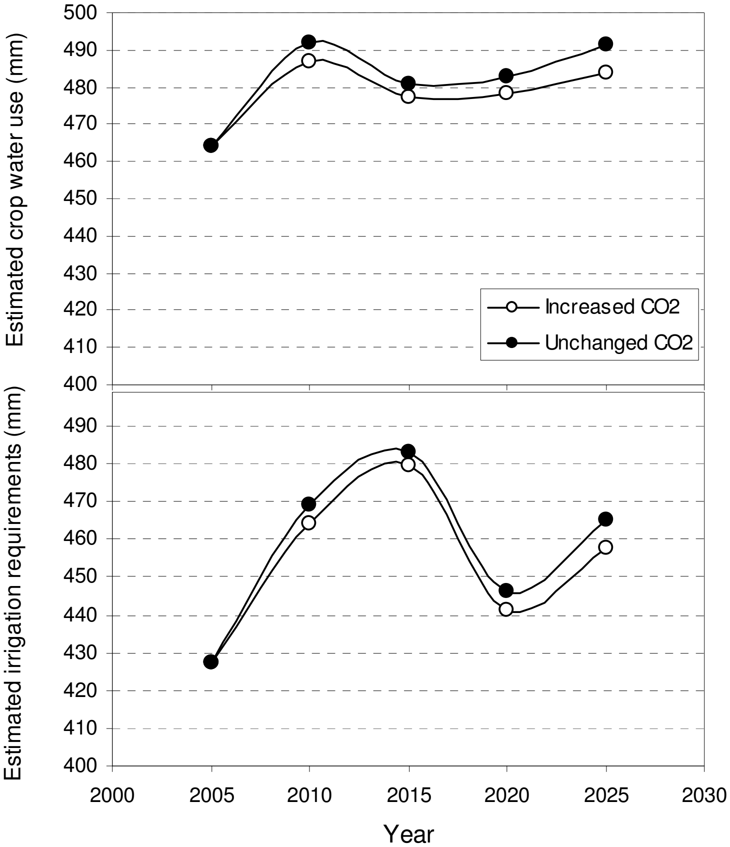

Figure 5. Evolution in crop water use and irrigation requirements for increased and unchanged CO_2 throughout the considered climate change period (2010-2025)

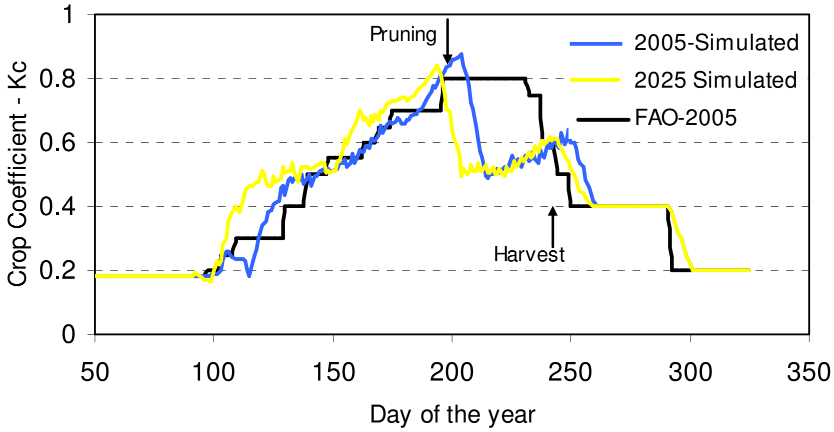

Figure 6. Seasonal patterns of crop coefficients (Kc) as traditionally used in field experiments (FAO-2005), and those simulated by CropSyst for 2005 and 2025. Arrows signals indicate when commercial summer pruning and harvest occurs.

Crop coefficients used to irrigate commercial orchards (Girona et al., 2006) were very well mimicked by CropSyst simulation during 2005 until the event of commercial summer pruning which is seldom considered for irrigation adjustment in commercial practices (Figure 6). But perhaps most important effect of rising temperatures, rather than increasing annual crop water requirements, is the way in which irrigation will have to be adapted through the season. The 2025 scenario, suggested substantial increases in crop coefficients early spring by 0.2 as a result of hastened crop development by increased temperatures (Figure 6). Later on the season (during June) predictions in crop coefficients were less different than what is actually being used in to irrigate vines (Figure 6). Another factor that will be probably modified is the moment of application of summer pruning. This will probably have to be applied earlier.

In summary, the effect of global warming on vine grape irrigation requirements will not represent a heavy burden on the irrigation districts (8% increase), because the increase in crop water demand during certain periods of the year (i.e. early spring) will be compensated by decreases in potential consumption after summer pruning being applied and the earliest event of harvest. However, crop coefficients used for irrigation scheduling will require substantial adjustment since vine growth will occur sooner and in a faster fashion early spring, which is a period very sensitive to water stress for grape production.

Literature cited

Allen, R.W., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No 56. 300 pp.

Flato, G.M. and G.J. Boer, 2001: Warming Asymmetry in Climate Change Simulations. Geophys. Res. Lett., 28, 195-198.

Flato, G.M., Boer, G.J., Lee, W.G., McFarlane, N.A., Ramsden, D., Reader, M.C., and Weaver, A.J., 2000: The Canadian Centre for Climate Modelling and Analysis Global Coupled Model and its Climate. Climate Dynamics, 16, 451-467.

Girona, J., Mata, M., del Campo, J., Arbones, A., Bartra, E., Marsal, J. 2006. The use of midday leaf water potential for scheduling deficit irrigation in vineyards. Irri. Sci.24:115-127.

Girona, J., Mata, M., Fereres, E., Goldhamer, D.A., Cohen, M. 2002. Evapotranspiration and soil water dynamics of peach trees under water deficits. Agric. Wat. Manag. 54:107-122.

IPCC, 2001: Climate Change 2001: The Scientific Basis. J.T. Houghton et al. (eds.), Cambridge University Press, 881pp.

Mavromatis, T., Hansen, J.W. 2001. Interannual variability characteristics and simulated crop response of four stochastic weather generators. Agric. For. Meteorol. 109:283-296.

Mavromatis, T., Jones, P.D. 1998. Comparison of climate scenario construction methodologies for impact assessment studies. Agric. For. Meteor. 91:51-67.

Merritt, W. S., Younes, A., Barton, M., Taylor, B., Cohen, S., Neilsen, D. 2006. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia. J. Hydrol. 326:79-108.

Richter, G.M. & Semenov, M.A. 2005. Modelling impacts of climate change on wheat yields in England and Wales - assessing drought risks. Agricultural Systems. 84, 77-97

Saxton, K.E., Rawls, W.J., Romberger, J.S., Papendick, R.I. 1986. Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036.

Semenov, M.A. & P.D. Jamieson. 2001. Using weather generators in crop modelling. In Sivakumar, M.V.K. (Ed.) Climate Prediction and Agriculture, Proceedings of the START/WMO International Workshop held in Geneva, Switzerland, 27-29 September 1999, Washington D.C. USA, International START Secretariat, 322 pp.

Semenov, M.A., Barrow, E.M. 2002. LARS-WG. A stochastic weather generator for use in climate impact studies. User Manual. Rothamstead Research, Hertfordshire, 27 pp.

Semenov, M.A., Brooks, R.J., Barrow, E.M., Richardson, C.W. 1998. Comparison of the WGEN and LARS-WG stochastic weather generators in diverse climates. Climate Research. 10:95-107.

Stökle, C.O., Donatelli, M., Nelson, R. 2003. CropSyst, a cropping systems simulation model. Europ. J. Agronomy. 18:289-307.

Wilby, R.L. & T.M.L. Wigley. Down-scaling general circulation issues in climate prediction. In Sivakumar, M.V.K. (Ed.) Climate Prediction and Agriculture, Proceedings of the START/WMO International Workshop held in Geneva, Switzerland, 27-29 September 1999, Washington D.C. USA, International START Secretariat. p 39-68.

Willmott, C.J. 1982. Some comments on the evaluation of model performance. Bulletin American Meteorological Society. 63(11): 1309-1313.