EXAMPLE OF CROP MODEL APPLICATION TO EVALUATE IRRIGATION STRATEGIES IN SUNFLOWER

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SUMMARY

An applicative use of a crop simulation model has been carried out to optimize irrigation scheduling in sunflower cropped in Southern Italy. Calibrated and validated in previous studies, EPIC model was implemented to run 45-years of simulations (with daily measured climatic data) in 51 scenarios, descending from combination of irrigation time (at five fixed data), seasonal amount (0, 50, 100 and 200 mm) and number (0 to 4).

The main results indicate: i) the superiority of single or double irrigation in the central phase (bud flower, beginning of flowering) for seed and biomass yield; ii) the optimal value of seasonal irrigation water amount about 250-300 mm for the highest water use efficiency value; iii) the highest profitability for the farmer with a single irrigation of 200 mm at bud flower phase and a negative increment of net income with irrigation at sowing or at seed ripening phases.

EPIC model, thanks to its submodels (growth, weather, soil, management, water, erosion, economics,..) revealed itself a useful tool to compare several management strategies, saving time and money. This approach could be used profitably at farm level or to a larger area scale.

Introduction

In semi-arid environments, where water resources are limited, it is important to optimise irrigation scheduling, with the aim to maximise economic water use efficiency and, at the same time, to reduce wastes. For this purpose, crop simulation models, once calibrated and validated on experimental data, can help farmers to choose the irrigation strategies taking into account the multiple interactions among soil, climate, genotype and crop management.

Among these, EPIC model (Williams *et al*., 1984) has been used as a support to irrigation scheduling in several environments and crops: wheat, a usually rainfed crop (Debaeke, 1995), maize (Cabelguenne *et al*., 1993) and sunflower (Texier *et al*., 1992) in Southern France.

In Italy, EPIC has been calibrated and validated in different environments and for several herbaceous crops (Ceotto *et al*., 1993; Rinaldi and Ventrella, 1997; Ventrella and Rinaldi, 1998). The results showed a good capability of the model to simulate sunflower and grain sorghum yield but poor performances for durum wheat and soybean. Further studies were conducted on sunflower crop to test EPIC's water sub-model (Rinaldi *et al*., 1998): the good results obtained, especially in simulating seasonal actual evapotranspiration and soil water content, induce us to use EPIC model in an applicative approach.

The aim of this work is to find the best irrigation strategy for sunflower cropped in a semi-arid Mediterranean region matching at the same time the following objectives: i) to use a reduced seasonal irrigation water amount; ii) to increase irrigation water use efficiency and iii) to reach the best profitability for farmer.

Materials and methods

The EPIC model (Erosion Productivity Impact Calculator) was developed to investigate the relationship between erosion and soil productivity and was subsequently enhanced by further addition of modules to improve simulation of plant growth (Williams *et al*., 1989). The climatic and soil data for the simulation were collected at the experimental farm of the Institute located at Foggia (41° N, 3° E, 90 m a.s.l.), in Southern Italy. The soil is a vertisol, silty-clay of alluvial origin. The climate is characterised by temperatures which may fall below 0°C in winter and rise above 40°C in summer and rainfall, unevenly distributed throughout the year, mostly concentrated in winter months.

The simulation was performed for the period 1st January - 31st December, using a 45-year climatic data set collected from 1953 to 1997. Measured daily values of temperatures, rainfall and global radiation were used as inputs of the model. Penman-Monteith model was used to estimate potential evapotranspiration.

Several irrigation strategies were simulated, descending from combination of irrigation time (fixed data in correspondence with five phenological phases, according to Schneiter and Miller, 1981), irrigation number and seasonal irrigation water amount (Table 1). A rainfed (no irrigation) treatment was also considered.

Fixed data of crop management were implemented in input files, according to local practice. Crop parameters, referred to "Romsun HS 90" hybrid, were obtained from previous validation and calibration studies.

The following output variables of the model were analysed: economic yield (YLD, in t ha^{-1}) and total biomass (in t ha^{-1}). Water use efficiency (YLD/ETa, in kg ha^{-1} mm^{-1}, with ETa as actual evapotranspiration) and irrigation water use efficiency [(YLD-YLD$_{rainfed}$)/IRGA, in kg ha^{-1} mm^{-1}, with IRGA as seasonal irrigation water] were calculated.

Economic submodel of EPIC is based on user inputs of crop management costs (ε ha^{-1}), seed purchase price (ε kg^{-1}) and seed population (kg ha^{-1}) to calculate the overall production specific cost, in this case, for the trial environment; it uses the seed and residues yield multiplied by their price to calculate the total marketable production and from their difference net income was obtained (NI in ε ha^{-1}).

Results and discussion

Yields

The sunflower seed yields, as simulated by EPIC model for 45 years, was in general similar to the local pluriannual average even for the rainfed treatment yield (2.2 t ha^{-1} of seed).

About irrigation timing, the most sensitive phenological stage was the bud flower emission (C in the figures). The results indicate, in average of 50, 100 and 200 mm of irrigation, a significant superiority of C (3.43 t ha^{-1} of yield) with respect to D and B phases (2.97 and 2.70 t ha^{-1}, respectively) while the lowest values were obtained with the irrigation at E and at A phases (2.30 and 2.27 t ha^{-1}) (Table 2). This is according to knowledge about critical phase for water stress in sunflower (Quaglietta Chiarandà and d'Andria, 1994).

EPIC model simulated a sunflower seed yield higher with a single irrigation at C than at other phases, especially with larger water amount. In the Fig.1, a largest difference going from 50 to 200 mm of irrigation amount is evident: in fact, at 50% of probability level with 50 mm, the values ranged from 2.2 (A and E phases) to 2.9 (C) while with one irrigation of 200 mm the yield values ranged from 2.2 to 4.4 t ha^{-1}. The initial water reserve, the seasonal rainfall and the irrigation when the soil water reserve was depleted, can explain the adequate soil moisture level from sowing through crop physiological maturity.

The single irrigation (50, 100 or 200 mm) at sowing or at milk ripening phase did not produce any increase with respect to rainfed strategy, considering both seed and biomass yield. The high soil water availability at sowing (for winter rainfall), caused copious sub-flow percolation and it was not enough to guarantee an adequate water supply for all seasonal crop cycle. In the second case, the irrigation was delayed and the sunflower suffered yet from a severe stress.

Sunflower seed and biomass yields increased linearly with the number of irrigations: with two irrigations, the combinations in the middle of the crop cycle and at maximum leaf area development, resulted as the most productive. In fact, a probability greater than 50% to obtain a yield value greater than 4 t ha^{-1} was obtained with CD and BC combinations (Fig. 2). Moreover, when using 50 mm for each irrigation, the model output showed an average of 3.3 t of seed ha^{-1}; this value increased up to 4.1 t ha^{-1} using 100 mm of each irrigation amount.

Water Use Efficiency

It is a characteristic of each crop, depending on sowing time, water availability, plant size; in the EPIC model simulation, Y_{WUE} ranged from 8.3 to 10.5 kg of seed yield ha^{-1} mm^{-1} of used water, in agreement with the other authors (Jones, 1984; Connor *et al*., 1985).

In relation to irrigation time, Table 2 shows the superiority of Y_{WUE} at flower bud phase and the lowest values at sowing and milk ripening phases, which is explainable by a better water satisfaction. A quadratic relationship between Y_{WUE} and seasonal irrigation water amount was obtained, with a maximum at 400 mm. It increased linearly with the number of irrigations, showing the highest values when the seasonal irrigation water was split.

By examining the Y_{WUE} of irrigation water with respect to rainfed treatment ($YIRR_{wue}$), it appears a certain variability of the response. We can see that the highest values were recorded independently of number or seasonal amount of irrigation, but with a constant presence of C phase. The lowest values, on the contrary, was observed with the A and E phases.

Economics

A minimum profitability of 50 ε ha^{-1} was obtained for sunflower cropped without irrigation. In particular, it is pointed out that in a water-limited environment, with a single irrigation the income already doubles with respect to the rainfed treatment (Table 2). On the other hand, if the sunflower is irrigated at sowing or at milk ripening stage, the profitability is

lower than rainfed, while it linearly increases if the crop is irrigated at B (91 ε ha^{-1}), at D (155 ε ha^{-1}) and, at least, at C stage (242 ε ha^{-1}).

Net income increased linearly with seasonal irrigation amount from 50 through 200 mm, while decreased from 500 (maximum value of 188 ε ha^{-1}) to 1000 mm. About irrigation number, few differences were obtained.

Conclusions

Simulation results indicate that the bud flower is the most responsive stage, regarding to the irrigation time to optimize the sunflower yield. In fact, when seasonal irrigation water is limited (max 200 mm), one or two irrigations in the central phase are profitable, either as irrigation use efficiency or net income. It is important, however, to ensure a good soil moisture at sowing. The maximum net income has been achieved with one irrigation of 200 mm at C phase or two irrigations of 100 mm each, at C and D phases.

The splitting of seasonal water amount produced a certain yield improvement, especially for the reduction of water drainage and consequently for a greater soil water availability.

EPIC model resulted as a good basis for decision support, at the farm level. In fact, it provides reliable estimates of the costs and benefits of the irrigation management and other agricultural practices (fertilisation, soil tillage) or environmental characteristics (climate change, soil fertility, soil erosion).

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Table 1 – Irrigation strategies simulated with EPIC model.

Irrigation number	Irrigation amount	Total seasonal amount	Phases [(1)]
1	50	50	A, B, C, D, E
	100	100	“
	200	200	“
2	50	100	AB, AC, AD, AE, BC, BD, BE, CD, CE, DE
	100	200	“
3	50	150	ABC, ABD, ABE, ACD, ACE, ADE, BCD, BCE, BDE, CDE
4	50	200	ABCD, ACDE, ABDE, ABCE, BCDE

[(1)] A = sowing time, 16th April; B = 6th true leaf, 20th May; C = bud flower, 16th June; D = flowering, 5th July; E = milk ripening, 25th July. The dates come from long-term trials averages.

Table 2 – EPIC simulation results as a function of number, amount and time of irrigation in sunflower (45 years average).

	Measured yield (t ha^{-1})	Yield (t ha^{-1})	Biomass (t ha^{-1})	Y_{WUE} (kg ha^{-1} mm^{-1})	$YIRR_{WUE}$ (kg ha^{-1} mm^{-1})	Net income (ε ha^{-1})
Rainfed	1.75 (1)	2.20	9.62	9.09	0.00	50
Irrigation time (one irr.)						
A Sowing	1.94 (2)	2.27	9.86	8.72	1.00	12
B Sixth flower	-	2.70	11.20	9.43	5.33	91
C Flower bud	-	3.43	13.19	10.17	11.17	242
D Flowering	-	2.97	11.67	9.28	7.17	155
E Milk ripening	-	2.30	9.95	9.16	1.17	14
Irrigation amount						
50 mm	-	2.52	10.59	9.24	6.40	60
100 mm	2.12 (3)	2.79	11.43	9.45	5.93	84
150 mm		3.36	12.85	9.55	5.44	105
200 mm	2.78 (3)	3.24	12.60	9.64	5.21	121
Irrigation number						
One irrigation	-	2.73	11.17	9.35	4.57	103
Two irrigations	-	3.04	12.06	9.54	5.57	114
Three irrigations	-	3.26	12.68	9.68	5.30	106
Four irrigations	3.34 (2)	3.46	13.22	9.78	6.30	93

(1) D'Andria et al., 1995; (2) Rinaldi (unpublished data); (3) Rinaldi and Rizzo, 1999.

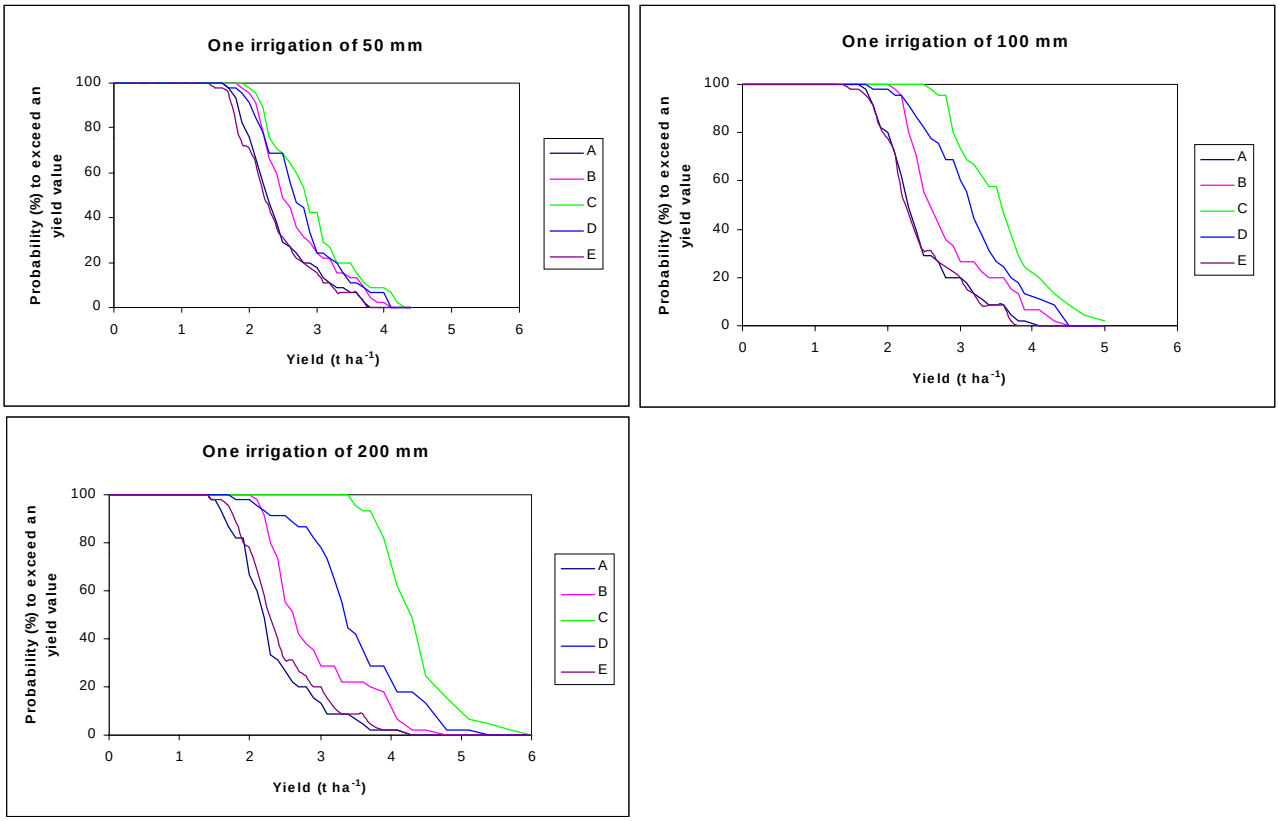

Figure 1 - Probability to exceed a yield value using a single irrigation strategy in sunflower, as simulated by EPIC model. A = sowing time; B = 6th true leaf; C = bud flower; D = flowering; E = milk ripening. Fixed dates coming from long-term trials averages.

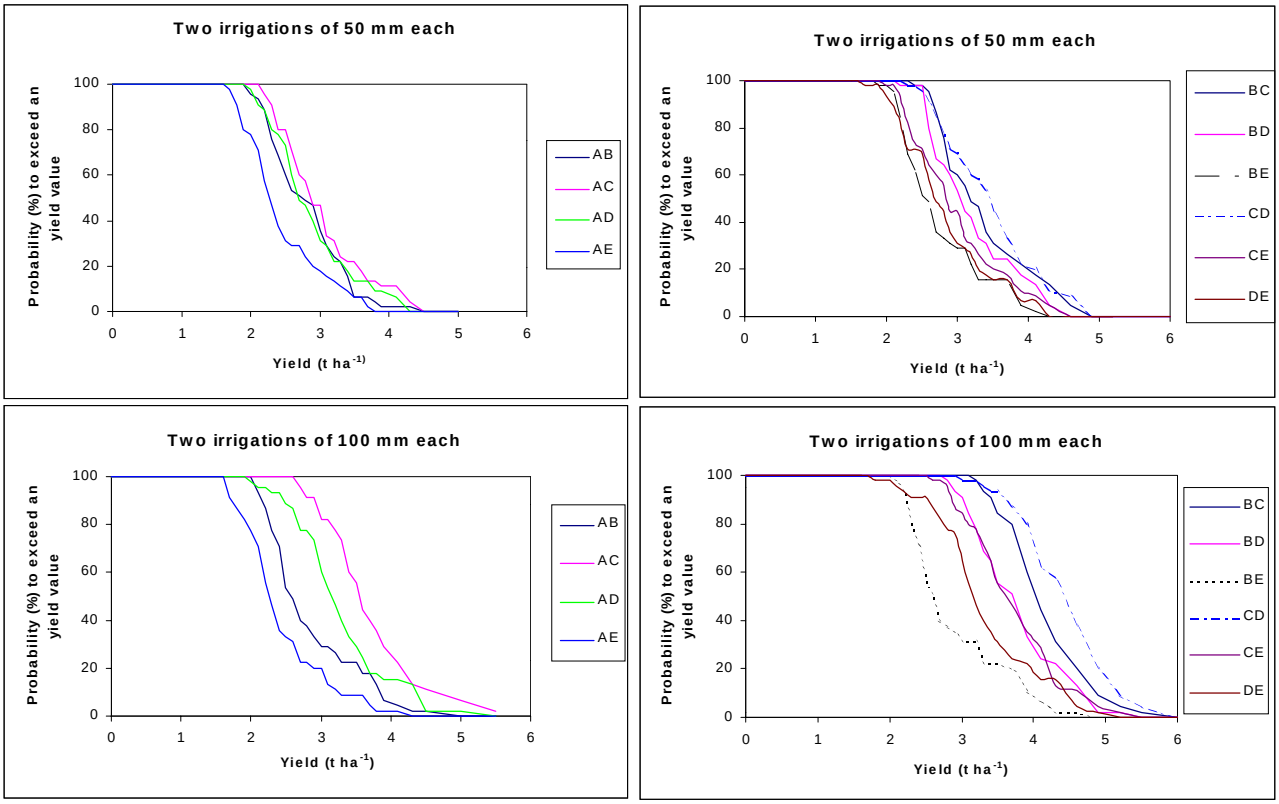

Figure 2 - Probability to exceed a yield value using two irrigation (of 50 and 100 mm each) strategies in sunflower, as simulated by EPIC model.