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The Future of Olive Plantation Systems on Sloping and Mountainous Land; Scenarios for Production and Natural Resource Conservation.

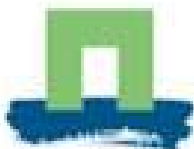
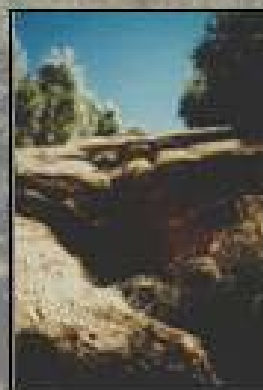
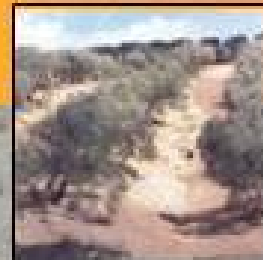
“OLIVERO”

Project Communication - No. 14

Analysis of hydrological fluxes and optimum dates for killing cover crops in the study areas

March 2006

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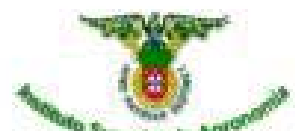
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1. INTRODUCTION

Deliverable 13 addresses the issue of hydrological features of water balances of



Figure 1: Location of the study areas for DL12

of olive orchards within the research areas, and Deliverable 15 the determination of optimum dates for killing cover crops that will provided the maximum soil protection against erosion while keeping a minimum risk of yield loss. These two tasks are aimed at different locations in the Mediterranean basin, Figure 1, with significant differences in climatic and soil conditions. These two deliverables were decided to be integrated in the Matera meeting

(September 2004) in a single analysis made trough a simple water balance model that will provide an estimation ob the basic hydrological fluxes and a criteria for determining the optimum date for killing cover crops. At the same meeting the different partners involved: IAS-

DL 13-14-15: Water Balance-Cover Crop

✓ Data required

	Dirn., dst	Eto, Rain	FC, Pw/P, soil type, prof, sbp	type, width	S. Manag.
GR	Yes	Yes H-irgreaves	Yes	Yes	Yes
CO	yes	Yes P-irnteihj	Yes	yes	yes
BA	Yes	Yes P-irnteihj	Yes	Yes	
CE	Yes	Yes Epan	Yes	Yes	

Figure 2: Basic information available to run the model

CIFA-IFAPA (Granada,

Spain), UNIBAS-SSCFA (Basilicata, Italy), and ISPOT-NAGREF (Crete, Greece) provided a summary of the available information available to apply the model, see Figure 2.

This report presents and describes the model developed for analyzing hydrological fluxes and optimum killing dates for cover crops in olive orchards, an evaluation of the model performance, and the results of the analysis made with the model for each partner for their corresponding SMOPS, with some general recommendations about managing cover crops in rain fed olive orchards.

2. WATER BALANCE MODEL

2.1. Model Description

Water Balance Model for Rainfed Olive Orchards with Cover Crop. OLIVCROP. Is a simulation model that calculates a daily water balance for the same conditions of soil, tree size and climate conditions for two different management:

- a) Cover crop in the lane between tree lines. The width and ground over within the strip of cover crop can be chosen by user.
- b) Alternative soil management to choose between conventional till or bare soil with herbicide

It is programmed in EXCEL. It is structured in three sheets. The first is used to introduce the inputs, and the third shows the model outputs. The second sheet contains detailed information and computations. Its main features are:

- a. Daily step.
- b. One-dimensional. It does not consider horizontal water fluxes, only vertical fluxes.
- c. It considers two soil layers. The first up to the rooting depth of the cover crop. The second up to the rooting depth of the olive tree.
- d. Tree transpiration is basically determined by the tree size for a given ETo.

- e. It computes separately soil evaporation from the bare soil, E_s , in the bare area of the orchard with cover crop and the orchard with alternative, bare soil, management.
- f. It computes cover crop ET based on the FAO methodology using published crop coefficient for two kind of cover crop.
- g. It calculates runoff from the orchard using the SCS, Curve Number methodology, with CN values developed for olive orchards
- h. The main factor in model design was easiness of use and development.
- i. It gives option for fixed date of cover crop killing or determination of such date by the model. The latest based on the criteria of maximum allowable difference on water content between the cover crop and the alternative soil management system.
- j. It is designed to study the effect on water balance of different dates of cover crop killing under variable soil, climate and orchard characteristics.

2.2. Model Inputs

a. Orchard characteristics:

- Distance between tree lines (m).
- Distance between trees within a tree line (m).
- Average tree canopy diameter (m).

Alternative soil management. It is used to evaluate the modification of water balance by the use of cover crop. Two options: conventional till or bare soil with herbicide

- Maximum allowable soil water deficit (mm).

It is defined as the maximum difference in soil water content between the cover crop system and a similar orchard with the alternative soil management before incurring in a risk of yield loss due to increased water use by the cover crop.

Three values are suggested as threshold: low risk 10 mm; moderate 20 mm; high 30 mm.

b. Cover crop characteristics:

- Type of cover crop. Two options: barley or naturally present grass.
- Width of the cover crop strip.
- % of ground cover by vegetation within the cover crop strip.
- Date for senescence. Date from which the model considers that cover crop ends its natural cycle when soil water dries up

c. Soil characteristics:

- Soil depth explored by olive tree (m).
- Soil hydrological group. According to the SCS.
- Soil water retention characteristics ($\text{cm}^3 \text{cm}^{-3}$). For saturation, field capacity, permanent wilting point and residual water content.
- Initial soil water content ($\text{cm}^3 \text{cm}^{-3}$) on September 1st: The model considers and homogeneous profile.
- Average slope steepness (%).

d. Sowing and killing dates for cover crop:

- Sowing date:

There are two options.

- a) To be fixed by the user.
- b) To be determined by the model.

In both cases emergence will occur only when favorable conditions, minimum of 20 mm rainfall in five consecutive days, exists.

- Cover crop killing date:

There are two options.

- a) To be fixed by the user.
 - b) To be determined by the model based on maximum allowable soil water deficit.
- e. Weather data:
- Daily rainfall and ET_0 (mm) from September 1st to August 31st

2.3. Model Definition

a. Soil water balance.

It is defined according to Equation 1, where P is rainfall, R runoff, D drainage, T tree transpiration, C cover crop evapotranspiration, E soil evaporation and ΔS modification of soil water storage, all in mm.

$$P=R+D+T+C+E+\Delta S \quad (1)$$

Daily rainfall is a model input that needs to be obtained from the nearest weather station.

Olive transpiration, T.

It is calculated according to Equation 2,

$$T_a = K_a * T_p \quad (2)$$

where K_a is a coefficient that reduces tree transpiration according to water deficit, defined according to Equation 3. T_p is the potential transpiration of an orchard according to Testi et al. (2006), Equation 4

$$K_a = \begin{cases} 1 & \theta_i \geq 0.5 * (\theta_{FC} + \theta_{PWP}) \\ \frac{(\theta_i - \theta_{PWP})}{((0.5 * (\theta_{FC} + \theta_{PWP})) - \theta_{PWP})} & \theta_i < 0.5 * (\theta_{FC} + \theta_{PWP}) \end{cases} \quad (3)$$

where θ_i is the volumetric soil water content of the soil layer, and θ_{FC} and θ_{PWP} are the volumetric soil water content corresponding to field capacity and permanent wilting point respectively.

$$T_p = K_p * ET_0 \quad (4)$$

where ET_0 is the potential evapotranspiration (mm) that is a model input, and K_p the coefficient of potential transpiration for olive tree defined by Equation 5.

$$K_p = Q_d * F_1 * F_2 \quad (5)$$

where Q_d is the fraction of radiation intercepted by the tree that can be approximated by the Beer-Lambert law, Equation 6.

$$Q_d = 1 - e^{(-K_r * V_u)} \quad (6)$$

where V_u is the tree canopy volumen by surface ($m^3 m^{-2}$) and K_r the coefficient of radiatio extintion given, for olive tree, by Equation 7.

$$K_r = 0,52 + 0,79 * 10^{-3} * D_p - 0,76e^{-1,25 * L_d} \quad (7)$$

where D_p is the tree density (olives ha^{-1}), and L_d the leaf area density ($m^2 m^{-3}$) that can be related to canopy volume, V_c , by Equation 8.

$$L_d = 2 - \frac{V_c - 20}{100} \quad (8)$$

In Eq. 5 F_1 and F_2 are empirical factors. F_1 depends on tree density

$$F_1=0,72 \quad \text{if} \quad D_p < 250 \text{ olives ha}^{-1}$$

$$F_1=0,66 \quad \text{if} \quad D_p > 250 \text{ olives ha}^{-1}$$

F_2 changes monthly according to Table 1.

Month	F_2	Month	F_2
January	0,70	July	1,25
February	0,75	August	1,20
March	0,80	September	1,10
April	0,90	October	1,20
May	1,05	November	1,10
Jun	1,25	December	0,70

Table 1: Monthly values of F_2

Evaporation from bare soil, E.

It is calculated based on the Ritchie model (Ritchie, 1972) that considers two different stages for evaporation. In stage 1, evaporation from a moist soil, evaporation is limited by the available energy; while in stage 2 evaporation is limited by soil hydraulic conductivity.

Evaporation in stage 1 is defined according to Equation 9.

$$E_s = ET_0 * (0,25 + (1 - Q_d) * 0,75) \quad (9)$$

where E_s (mm) is daily soil evaporation, ET_0 (mm) the potential evapotranspiration, and Q_d es radiation intercepted by olive canopies, Eq. 6. Stage 1 is abandoned when a fixed amount of water, U , has been evaporated. U depends on the soil type, ranging from 5-6 mm in well drained soils to 12-14 mm in heavy clay soils.

Evaporation in stage 2 is described according to Equation 10.

$$E_s = \alpha * (\sqrt{t} - \sqrt{t-1}) \quad (10)$$

where E_s (mm) is daily soil evaporation, and α a parameter related to the soil type but usually close to $3,5 \text{ mm day}^{-0,5}$, and t days from the end of stage 1.

3. Crop Evapotranspiration, C.

It is calculated according to Equation 11.

$$C = K_{cc} * ET_0 \quad (11)$$

where C (mm) is the daily crop evapotranspiration, ET_0 (mm) is the the potential evapotranspiration and K_{cc} the crop coefficient calculated according to Equation 12.

$$K_{cc} = K_{fao} * K_a * K_{rad} * K_t \quad (12)$$

where K_{fao} if the crop coefficient for barley according to FAO manual (Allen et al., 1998), K_a is the fraction of soil covered by the cover crop, K_{rad} the incoming radiation to the cover crop and K_t a factor that accounts for a 20% reduction in transpiration in the case of a cover crop consisting in natural weeds.

4. *Runoff, R.*

It is calculated daily according to the SCS CN number method, Equation 13.

$$\begin{aligned} Q &= \frac{(P - 0.2S)^2}{(P + 0.8S)} & P > 0.2S \\ Q &= 0 & P \leq 0.2S \end{aligned} \quad (13)$$

where R is event runoff, mm, P is event rainfall, mm, and S is initial abstraction, mm, defined by Equation 14, where CN is the Curve Number parameter to determine.

$$S = 254 \left(\frac{100}{CN} - 1 \right) \quad (14)$$

The CN number methods were developed for olive orchards at 5% slope by Romero et al. (2006) using a physically based runoff generation model, and validated against field data, are summarized in Table 2. CN values are corrected for slopes other than 5% according to Williams (1991).

Drainage, T.

The model computes as percolated water all the infiltrated water above field capacity.

SOIL MANAGEMENT	Soil hydrological class				C	D
	A	B	C	D		
No till with bare soil	<i>Tree cover</i>	<i>Tree cover</i>	<i>Tree cover</i>	<i>Tree cover</i>		
	<15%	>15%	<15%	>15%		
	77	74	86	84	90	94
Freshly tilled	<i>Tree cover</i>	<i>Tree cover</i>				
	<15%	>15%				
	61	58	72		76	80
Degraded tilled	<i>Tree cover</i>	<i>Tree cover</i>				
	<15%	>15%				
	71	75	81		88	90
Well established cover crop	$CN_2 = 77 e^{(-0.0208 C + 0.0001016 C^2)}$		$CN_2 = 85 e^{(-0.0072 C)}$		$CN_2 = 90 e^{(-0.0055 C)}$	$CN_2 = 94 e^{(-0.0037 C)}$
Poorly established cover crop	<i>Tree cover</i>	<i>Tree cover</i>				
	<15%	>15%				
	72	76	83		89	92

C is percentage of ground cover by cover crop. $CN_{III} = \text{MIN}(100, 3.3 + 1.05 CN_{II})$. $CN_I = \text{MAX}(0, -4.7 + 0.89 CN_{II})$.

Table 2: Proposed average- CN_{II} values for different hydrologic soil class and soil management at 5% slope. CN_I and CN_{III} from expressions below

2.4. Model Outputs

- Date of sowing
- Date of cover crop killing (if necessary).
- Components of the soil water balance at August 31st, and cover crop killing date for soil management systems.
 - Soil volumetric water content θ_i ($\text{cm}^3 \text{ cm}^{-3}$).
 - Rainfall (mm).
 - Evapotranspiration ET (mm).
 - Tree transpiration (mm).
 - Soil evaporation (mm).
 - Cover evapotranspiration (mm)
 - Runoff (mm).
 - Drainage.
- Graph with daily values of the components of the soil water balance from September 1st to August 31st

3. SENSITIVITY ANALYSIS

To evaluate the model sensitivity to their key parameters, we performed an analysis of sensitivity according the orchard characteristics described by the OLIVERO partners in their respective SMOPS (Metzidakis, 2004, Xiloiannis et al., 2004) and average climate characteristics of several locations among the geographical area involved, Figure 3, taken from a repository of climate information (IAUC, 2005).



Figure 3: Average climate characteristics for the locations involved in the model analysis

	<i>Plant density, tree/ha</i>	<i>Canopy diameter, m</i>	<i>Slope steepness, %</i>	<i>Soil texture</i>	<i>Soil depth, m</i>	<i>Top soil OM %</i>
ISPOT-NAGREF (Crete, Greece)	Irrigated: 200-300	Irrigated: <5	Moderate	Sandy-loam	1	3.4-2.1
	Rain fed: 50-80	Rain fed: 8-5	Steep	Clay-loam	>1.2	
	70-200	>8	Terraces	Sandy-clay-loam		
CIFA-IFAPA (Granada, Spain)	Traditional: 107-122	NA	7->30	Silty-clay	NA	2.4-1.4
	Intensive			loam		
	Irrigated: 175			Silty-loam Silty-clay Clay		
IAS-CSIC (Cordoba, Spain)	SMOPS 1-4: 130-136	SMOPS 1-4: 3.0	SMOPS 1-4: 17-60	Sandy-loam	SMOPS 1-4: 1	4-1
	SMOP 5: 128	SMOP 5: 5.1	SMOP 5: 5-25%	Loam	SMOP 5: 2	
				Loam-sandy Silty-sandy		
UNIBAS-SSCFA (Basilicata, Italy)	Extensive: 70-150	NA	>20-<10	Loam	NA	2.5-1.2
	Intensive: >200			Clay-Loam Clay		

Table 3: Summary of orchard characteristics at the study areas. NA means no available.

In all the simulations presented in this section we used an “average” orchard extracted from analysis of the different types presented in Table 3. This allows understanding of

OLIVE ORCHARD	
1. Distance between olive rows (m):	10
2. Distance between olive trees within the row (m):	10
3. Olive tree mean canopy diameter (m):	6
4. Alternative soil management: (choose one option)	2
<input type="checkbox"/> Zero till using no tillage combined with herbicide (1) <input type="checkbox"/> Conventional Tillage (2)	
5. Maximum allowable difference in soil water content between orchard with cover crop and orchard with alternative management (mm):	10
(Use the amount that you consider will not incur in significant yield loss compared to the alternative management, by default use 20 mm) Minimum value 10 mm Low risk: 10 mm Medium risk: 20 mm High risk: 30 mm	
COVER CROP	
6. Type of cover crop (barley-1, natural grass-2):	1
7. cover crop width (m):	4
8. Ground cover within the cover crop strip by vegetation (%):	100
9. Day from which the model allows death of cover crop for lack of soil water:	60

the model behavior under modification of a given parameter for the configuration more probable among the different areas, while at the same time maintains the number of simulations limited. The orchard characteristics are summarized in Figure 4, and soil and slope characteristics in Figure 5.

Figure 4: Orchard characteristics used in section 3.

SOIL																																																				
10. Soil depth (m): (Write your best estimate of soil depth, see below for orientation)	1.5																																																			
<input type="checkbox"/> Olive plantation on sloping land - 1,2 m <input type="checkbox"/> Olive plantation on Campiña - 2,5 m																																																				
11. Hydraulic soil group:	c																																																			
A: Low runoff potential. Soils with high infiltration rates. Usually sandy, deep, well drained soils. Minimum infiltration rate higher than 7.62 mm h ⁻¹ B: Moderate infiltration rate. Usually well drained soils with fine, moderately fine to moderately coarse texture. Minimum infiltration rate between 3.81- 7.62 mm h ⁻¹ C: Low infiltration rate. These are soils that contain a layer that impedes downward movement of water. Such soils are moderately fine to fine textured. Minimum infiltration rate between 1.27- 3.81 mm h ⁻¹ D: Higher potential runoff. Infiltration is very low when soil is wet. Such soils are primarily clay soils with high swelling potential, soils with a permanent high water table, or soils with a limitation to soil water movement very near to the surface. Minimum infiltration rate smaller than 1.27 mm h ⁻¹																																																				
12. Volumetric water content (cm ³ /cm ³): (Write your best estimate of volumetric water content, the next table shows orientation values for different type of soil)																																																				
Residual water content (cm ³ cm ⁻³)	0.03																																																			
Water Content pwp (cm ³ cm ⁻³)	0.14																																																			
Water Content fc (cm ³ cm ⁻³)	0.31																																																			
Water Content sat (cm ³ cm ⁻³)	0.40																																																			
<table border="1"> <thead> <tr> <th rowspan="2">Texture</th> <th rowspan="2">Bulk density (gcm⁻³)</th> <th colspan="4">Volumetric Water content (cm³ cm⁻³)</th> </tr> <tr> <th>Residual water content</th> <th>P.W.F.</th> <th>F.C.</th> <th>Sat</th> </tr> </thead> <tbody> <tr> <td>Sandy</td> <td>1.65</td> <td>0.02</td> <td>0.07</td> <td>0.15</td> <td>0.30</td> </tr> <tr> <td>Sandy-loam</td> <td>1.50</td> <td>0.04</td> <td>0.09</td> <td>0.21</td> <td>0.34</td> </tr> <tr> <td>Loam</td> <td>1.40</td> <td>0.03</td> <td>0.14</td> <td>0.31</td> <td>0.40</td> </tr> <tr> <td>Clay-loam</td> <td>1.35</td> <td>0.08</td> <td>0.17</td> <td>0.36</td> <td>0.42</td> </tr> <tr> <td>Silty-clay</td> <td>1.30</td> <td>0.06</td> <td>0.20</td> <td>0.40</td> <td>0.43</td> </tr> <tr> <td>Clay</td> <td>1.25</td> <td>0.09</td> <td>0.21</td> <td>0.44</td> <td>0.45</td> </tr> </tbody> </table>							Texture	Bulk density (gcm ⁻³)	Volumetric Water content (cm ³ cm ⁻³)				Residual water content	P.W.F.	F.C.	Sat	Sandy	1.65	0.02	0.07	0.15	0.30	Sandy-loam	1.50	0.04	0.09	0.21	0.34	Loam	1.40	0.03	0.14	0.31	0.40	Clay-loam	1.35	0.08	0.17	0.36	0.42	Silty-clay	1.30	0.06	0.20	0.40	0.43	Clay	1.25	0.09	0.21	0.44	0.45
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Use default value:	0.18																																																			
14. Average slope steepness (%):	20																																																			

Figure 5: Soil characteristics used in section 3.

3.1. Sensitivity to climate conditions

Figure 6 shows the killing date predicted for the model for the seven locations among European locations indicated in Figure 3, in a year with average precipitation and evapotranspiration, allowing a maximum difference of 10 mm in soil water content between the cover crop system and an alternative system based on conventional tillage. Killing date of 365 means no need to kill the cover crop due to the lack of difference in soil water content with the option of an alternative management. Results indicates how the model is sensitive to changing environmental conditions, rainfall and evapotranspiration, predicting no need to kill the cover crop in an average year for an “average” rainfed orchard above a threshold around 800 mm rainfall per year. Below that threshold the model predicts for the simulated conditions optimum killing dates that goes from January 24th, day 113 for Heraklion, to March 21st, day 202 for Seville.

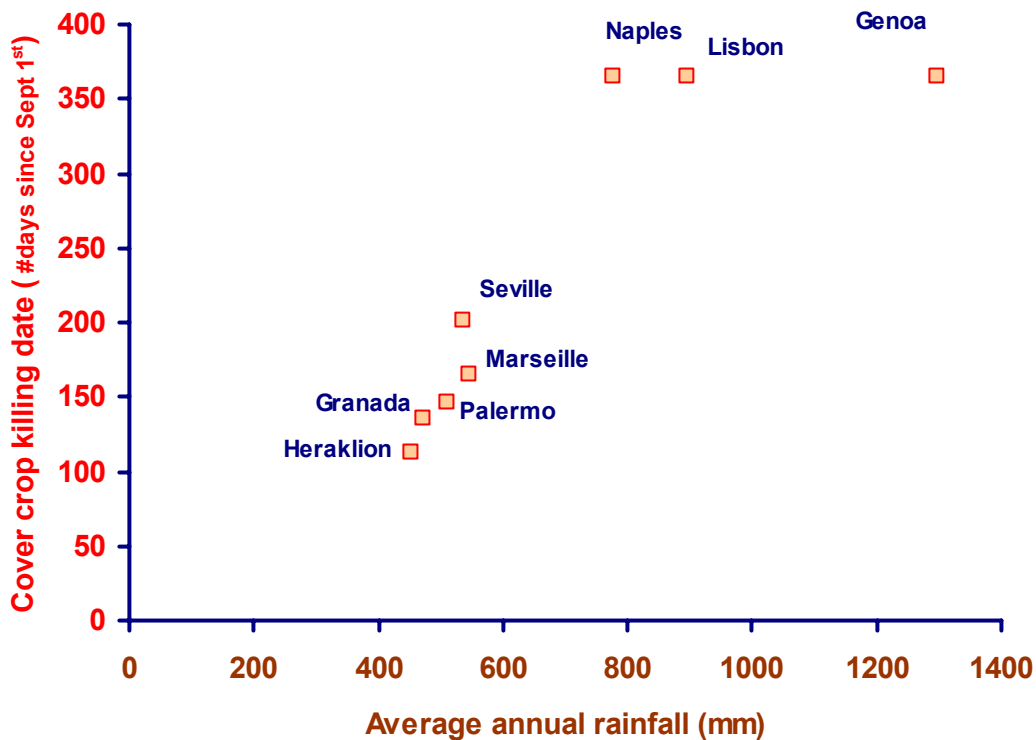


Figure 5: Killing dates predicted for cover crop at different locations in an average year allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

That difference in soil water content, maximum of 10 mm, means a moderate risk in yield losses due to reduced transpiration of the olive tree in a cover crop system compare with the alternative of a conventionally tilled orchard. Increasing the maximum allowable difference means reducing the killing date for the cover crop, data not shown, although at the cost on increased risk of yield losses due to reduction of olive tree transpiration due to competition for soil water between the olive tree and the cover crop.

A similar relationship is obtained comparing the ratio between average annual rainfall: annual potential evapotranspiration, Figure 6, suggesting that in the region studied and the conditions simulated the threshold that indicates no need to kill prematurely the cover crop is the precipitation that matches the potential evapotranspiration.

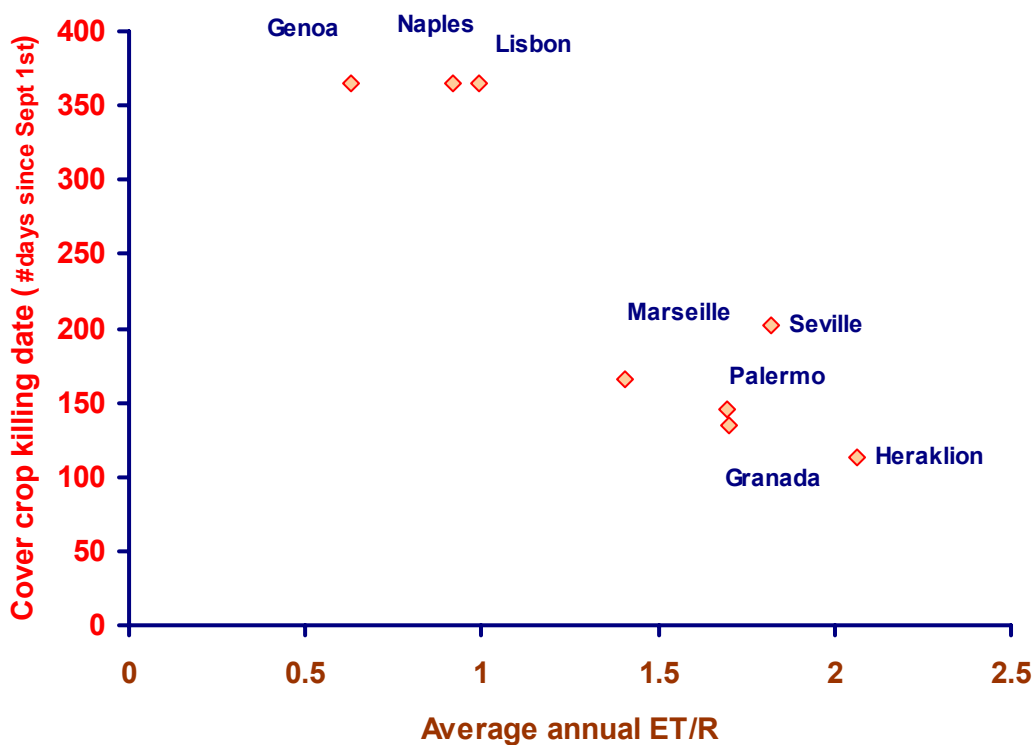


Figure 6: Killing dates predicted for cover crop at different locations in an average year allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

3.2. Sensitivity to seasonal distribution of rainfall

Results presented in section 3.1 correspond to simulations for an average year where rainfall has been evenly distributed within the rainy days corresponding to each month. For a given location rainfall varies from year to year not only in total amount but also in their distribution. Figure 7 presents the optimum dates for killing the cover crops for an orchard with the same characteristic of the one used in section 3.1 for a 20 year long record of daily ET and rainfall at Cordoba.

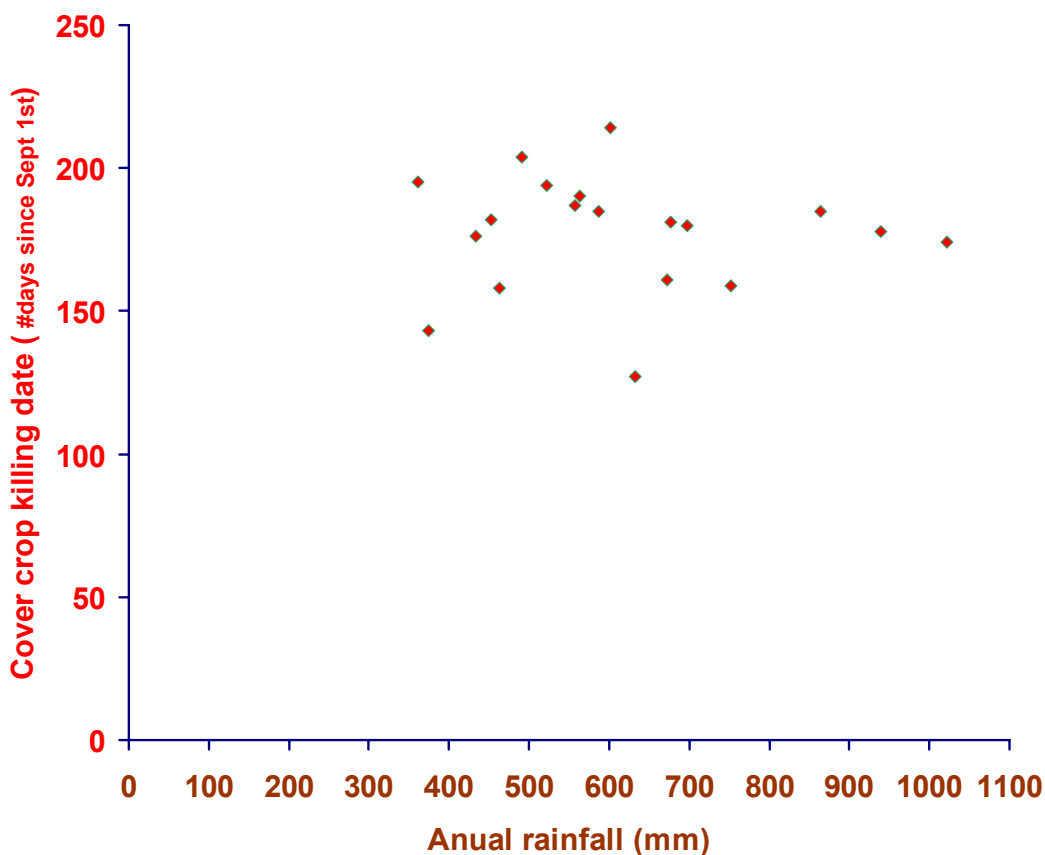


Figure 7: Killing dates predicted for cover crop at Cordoba for the same orchard simulated in section 3.1 for years varying in Et and rainfall allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

Results in Figure 7 indicates how for a given location year to year variability of killing date the cover crop, using the approach of limiting the maximum deficit between the actual cover crop system and the potential alternative of a bare soil system, is more related to rainfall distribution within the year rather than to total annual precipitation.

During a dry period in late winter or early spring without rainfall the cover crop will transpire significant amounts of water that will quickly develop a deficit in soil water compared to the alternative of a bare clean surface through conventional tillage. This situation is captured by the model as reflected in the results in Figure 7. Figure 7 also indicates how with the exception of very dry years, the optimum killing dates in Cordoba for the simulated conditions ranges from early February to early April with an average killing date in early March.

3.3. Sensitivity to the spatial extension of the cover crop

One strategy to reduce the risk of competition for soil water with the olive tree is reducing the area covered by the cover crop. This can be a strategy to pursue indifferent circumstances. For example as a conservative approach during the first years of implanting the cover crop systems until the farmer gets familiar with the system, or when trying to achieve at least a partial degree of soil protection in very dry areas.

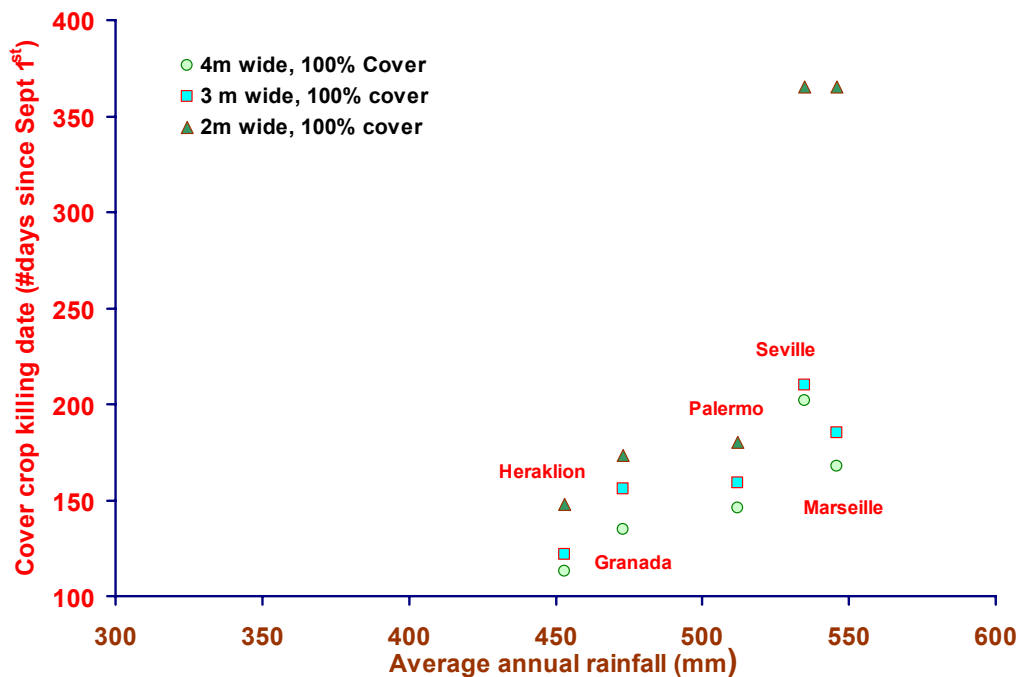


Figure 8: Killing dates predicted for different extensions of cover crop at different locations in Southern Europe for the same orchard simulated in section 3.1 for average years allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

Figure 8 shows how the killing dates of the cover crop predicted by the model for the locations considered in section 3.1, and 10 mm of maximum differences in soil water

between the cover crop and the conventional till alternative system, are significantly delayed decreasing the extension of the cover crop strip.

3.4. Sensitivity to soil depth explored by the olive tree.

Figure 9 shows the modification of the optimum killing dates for the cover crop, always for the orchard conditions simulated in section 3.1, when the soil depth explored by the olive roots decrease from 1.5 m to 0.75 m. The model predicts a delay in the optimum killing dates when soil depth is reduced. This is because the killing dates has been fixed by the model in relative terms, that is compared to the same situation but under conventional till management, and when soil depth is reduced losses by drainage increases more, in relative terms, in the cover crop system compared to conventional tillage management, Figure 10.

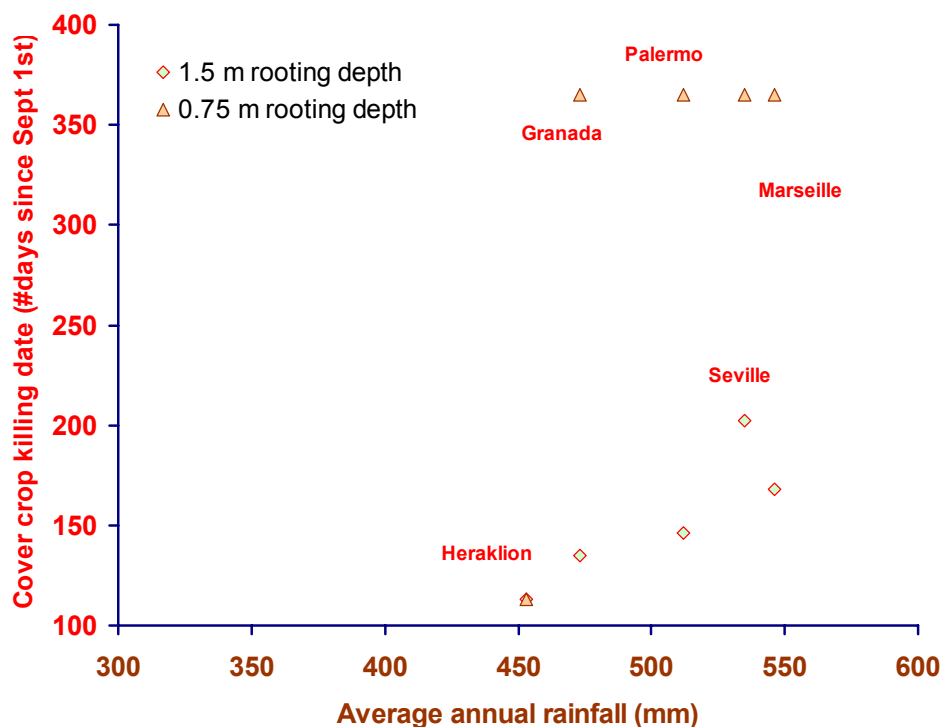


Figure 9: Killing dates predicted for two different rooting depths at different locations in Southern Europe for the same orchard simulated in section 3.1 for average years allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

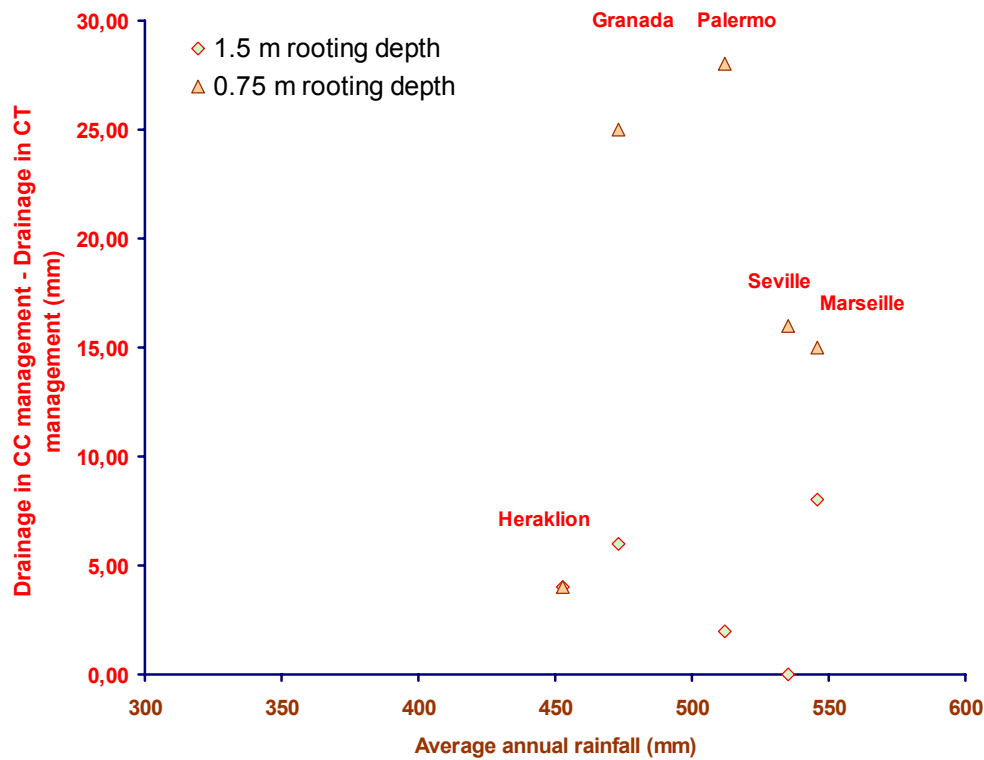


Figure 10: Differences in drainage between the conventional till, CT, and the cover crop management, CC, predicted for two different rooting depths at different locations in Southern Europe for the same orchard simulated in section 3.1 for average years allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system.

3.5. Sensitivity to soil type.

Figure 11, shows the modification of the optimum killing dates for the cover crop, always for the orchard conditions simulated in section 3.1, when changing the soil type. Changing soil type affects the moisture content limit used as input as well as the hydrologic soil group. The model predicts none or very minor changes in his killing date, what can be explained because the killing dates have been fixed by the model in relative terms, that is compared to the same situation but under conventional till management

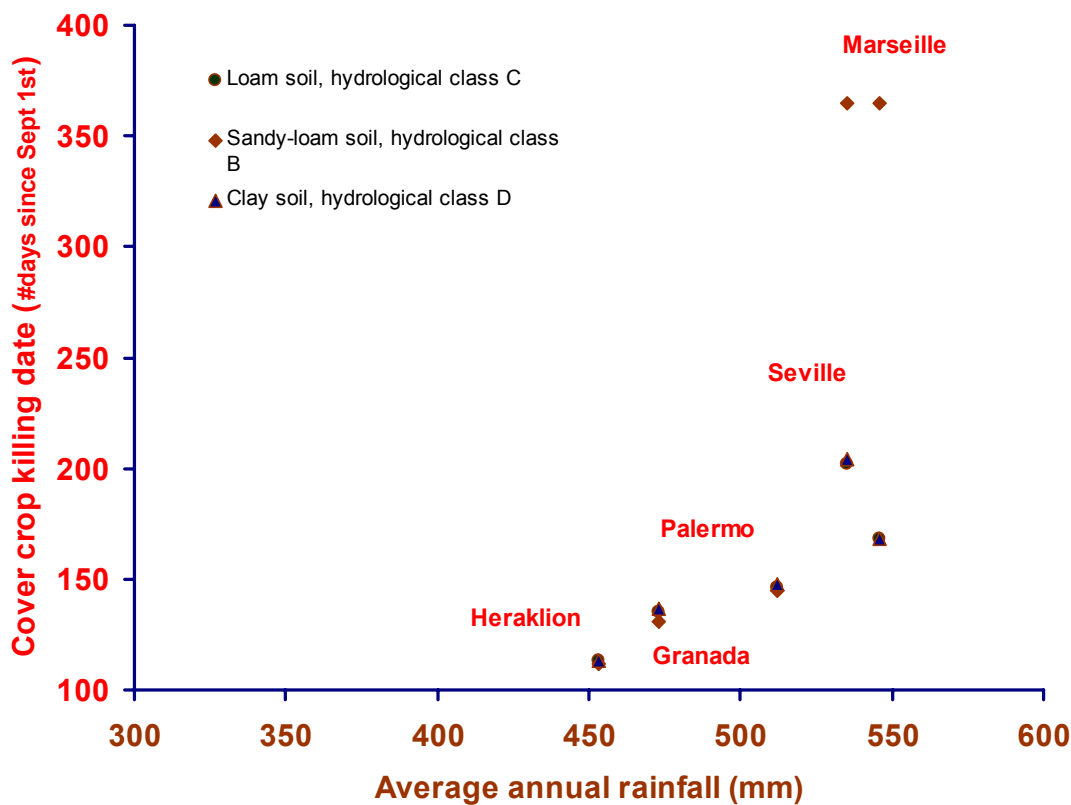


Figure 11: Differences in optimum killing dates predicted for three different soil types at different locations in Southern Europe for the same orchard simulated in section 3.1 for average years allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

3.6. Sensitivity to olive canopy size.

Reduced canopy size, while maintaining the other orchard characteristics, means reduced tree transpiration. Figure 12 shows the modification of the optimum killing dates for the cover crop, always for the orchard conditions simulated in section 3.1, when changing the soil type. The model predicts a significant delay in optimum killing dates for orchards with smaller trees that will present a lower transpiration demand.

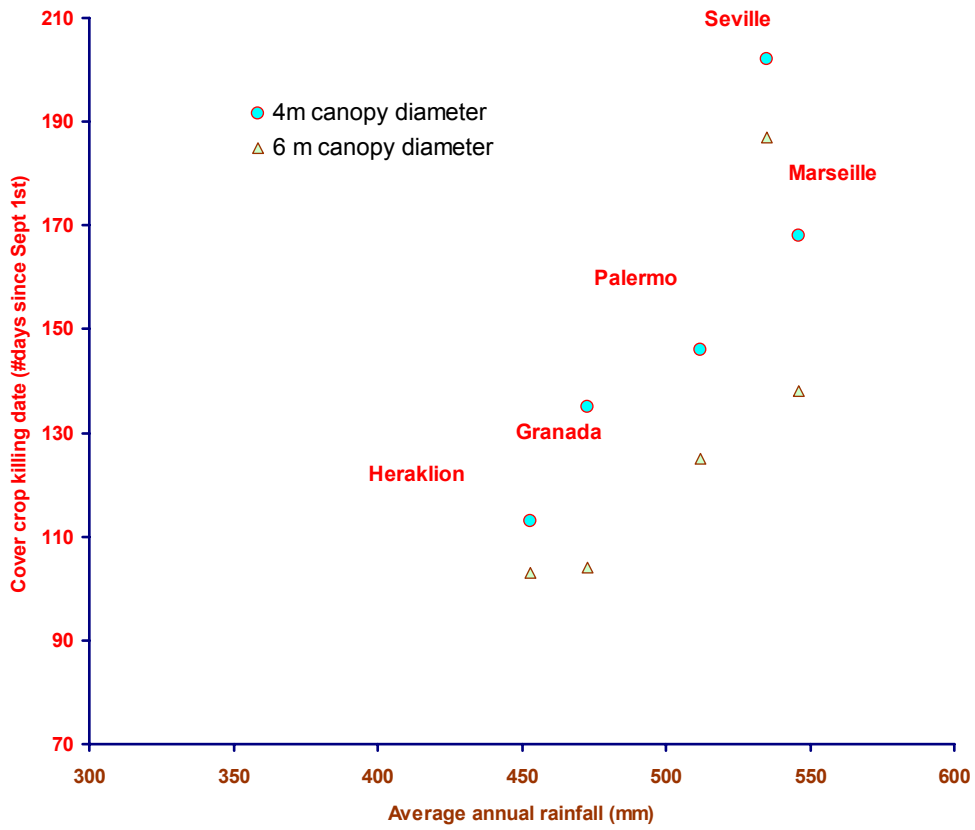


Figure 12: Differences in optimum killing dates predicted for three different canopy sizes soil types at different locations in Southern Europe for the same orchard simulated in section 3.1 for average years allowing a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

4. ANALYSIS OF CORDOBA STUDY AREA

4.1. Material and methods

The Cordoba study area deals with the study of organic olive orchards, mostly rainfed, and have been classified in five SMOPS fully describe in Metzidakis (2004) and Xiloiannis et al. (2004). The key SMOPS characteristics summarized in Table 4.

#	Municipalities	Tree density Tree/ha	Average Yield Kg/ha	Description
1	Hinojosa, Belalcazar, Peñarroya	136	864	Marginal plantations on sloping land and shallow soils in Northern half of Cordoba province
2	Pozoblanco, Obejo, Espiel	136	1014	Marginal plantations on sloping land and shallow soils in Northern half of Cordoba province
3	Adamuz, Montoro	135	990	Marginal plantations on sloping land and shallow soils in Northern half of Cordoba province
4	Villaviciosa	130	810	Marginal plantations on sloping land and shallow soils in Northern half of Cordoba province
5	Subbetica region	128	2831	Rainfed plantations on sloping land and moderately deep soils in Southern half of Cordoba province

Table 4: Brief description of SMOPS in Cordoba study area

These five SMOPS can be simplified in two: one are the marginal orchards on shallow soils in the Northern part of the province, hereafter Sierra, and the second the more productive rainfed plantations in the Southern part of the province on deeper soils and lees steep areas, hereafter Campiña. This has been recognizes in previous published studies on soil management and properties within the study area (Millgroom et al.,

2006). These two olive production areas also differ in climatic conditions with the Northern area having slightly higher average annual rainfall and lower potential evapotranspiration compared to the Southern olive production area (Xiloyannis et al., 2004; Gil et al. 2003).

For each of these two areas an average olive orchard was simulated based on the orchard description presented in Metzidakis (2004) and Xiloyannis et al. (2004) and summarized in Table 5.

Area	Tree spacing (m)	Canopy diameter (m)	Rooting depth (m)
Sierra	9x9	4	1.2
Subbetica	10x10	6	2

Table 5: Orchard characteristics simulated in the SMOPS analysis

For each of these areas a representative “average” soil profile was simulated based on the soil description provided by Millgroom et al. (2006) and Gil et al. (2003), Table 6.

Area	Soil texture	Hydrological class	Slope %
Sierra	Sandy-loam	C	25
Subbetica	Loam	C	15

Table 6: Soil characteristics simulated in the SMOPS analysis

In all the situations and analysis two different soil management options were evaluated: conventional till, and cover crop. In the cover crop management the cover crop strip width was 4-m in both areas, consisting in natural vegetation in Sierra and barley in Subbetica. OILCROP model was run with the option of determining the date for cover crop killing when differences in soil water content between the cover crop and the alternative conventional till system were larger than 10 mm.

For each area a representative location was selected for definition of the climatic conditions. These locations were Belmez (average annual rainfall 568 mm and average annual $ETO_{Penaman_monteith}$ 1237 mm) for Sierra and Albendin (average annual rainfall 479 mm and average annual $ETO_{Penaman_monteith}$ 1376 mm). Only average climate data

were available for these locations. To simulate annual variability 100 year long record was generated using CLIGEN (Nicks et al., 1995) calibrated from the average climatic data available assuming that the number of rainy days for both locations was the same, and converting $ET_{Hargreaves}$ calculated from the CLIGEN outputs into $ET_{Penmann-Monteith}$ using the coefficients developed for Andalusia by Vanderlinden et al. (2004). To maintain a reduced number of simulations eleven years were taken from the 100 years generated using CLIGEN in such way that included the variability in annual rainfall.

4.2. Comparison of killing dates for cover crops in both areas

Figure 14 presents the optimum dates for killing the cover crops at both study areas determined by OLIVCROP simulations.

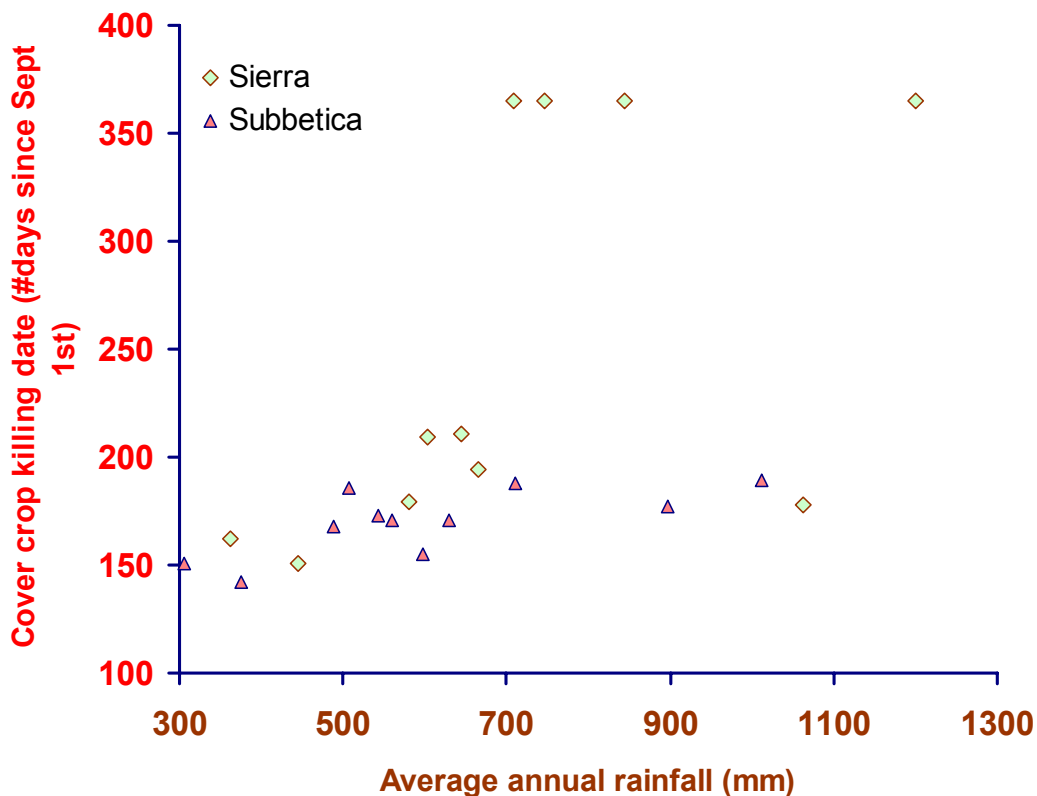
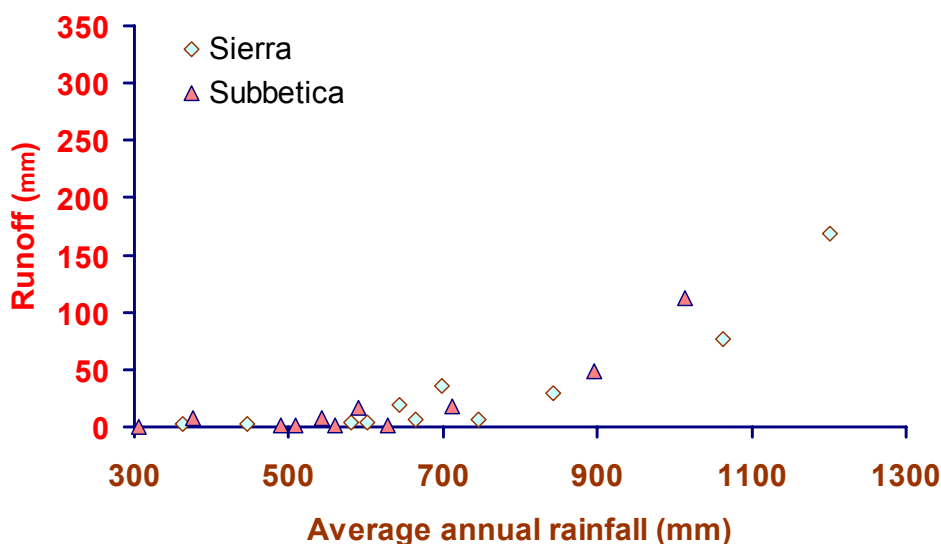


Figure 13: Optimum killing dates predicted for Sierra and Subbetica for years with different rainfall in Cordoba for a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

In Subbetica the model predicts no need to kill the cover crops in most of the years with total rainfall above 700 mm, and average killing date for the remaining years around mid March, although these dates vary since early February to early April. In Campiña the model predicts earlier killing dates, even in rainy years, with average killing date in late February, with these dates varying since late January to early March. These differences can be explained mainly by differences in rainfall between both areas, higher in Sierra, reduced tree canopy in Sierra, and reduced rooting depth in Sierra.

4.3. Hydrological fluxes in both areas.

Figure 14 shows the predicted annual runoff for both areas and cover crop management indicating moderate runoff losses, never above 11%. These moderate losses predicted by the model agree with the increased infiltration measured in olive orchards with cover crops (Millgroom et al. 2006, Gómez, 2005) and moderate runoff losses measured in runoff plots in different studies (Gómez et al. 2004; Gómez 2005).



al. 2006). This reduction in runoff when introducing a cover crop instead of conventional till is one of the reasons why it is possible the use of a cover crop without risking olive yield in rainfed orchards, the other been the importance of soil evaporation from the bare soil in the wet days. It is also key in reducing water erosion.

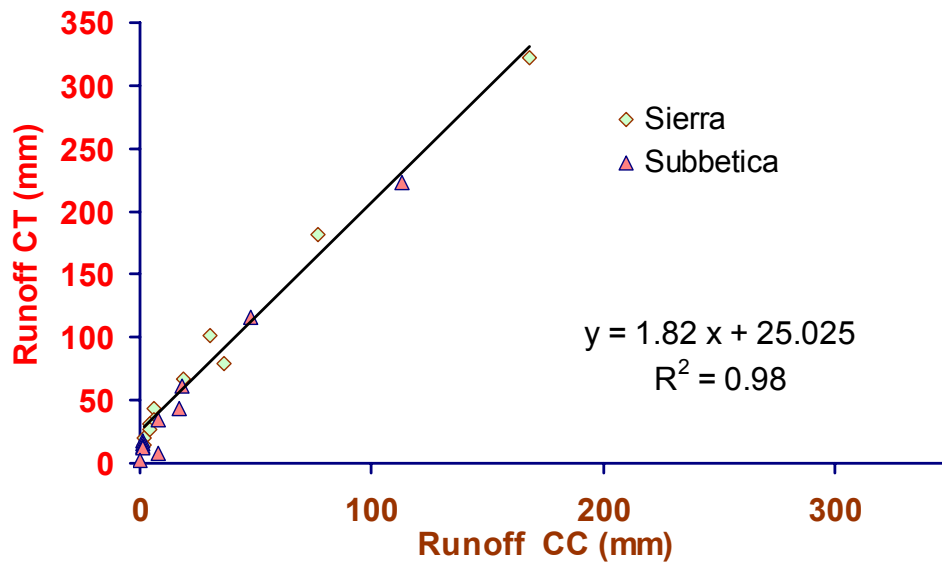


Figure 15: Comparison of annual runoff predicted for cover crop and conventional till in both areas.

Figure 16 shows the predicted tree transpiration for both areas and cover crop management for different years, indicating large differences between Sierra and Subbetica. These differences, roughly double tree transpiration in Subbetica compared to Sierra are proportional to differences in yield that in Subbetica are approximately twice the observed in Sierra, Table 4. Figure 16 also indicates how there is a stronger relationship between annual rainfall and predicted tree transpiration in Sierra compared to Subbetica. This can be explain by the reduced soil water storage capacity due to reduced rooting depth and soil texture in Sierra.

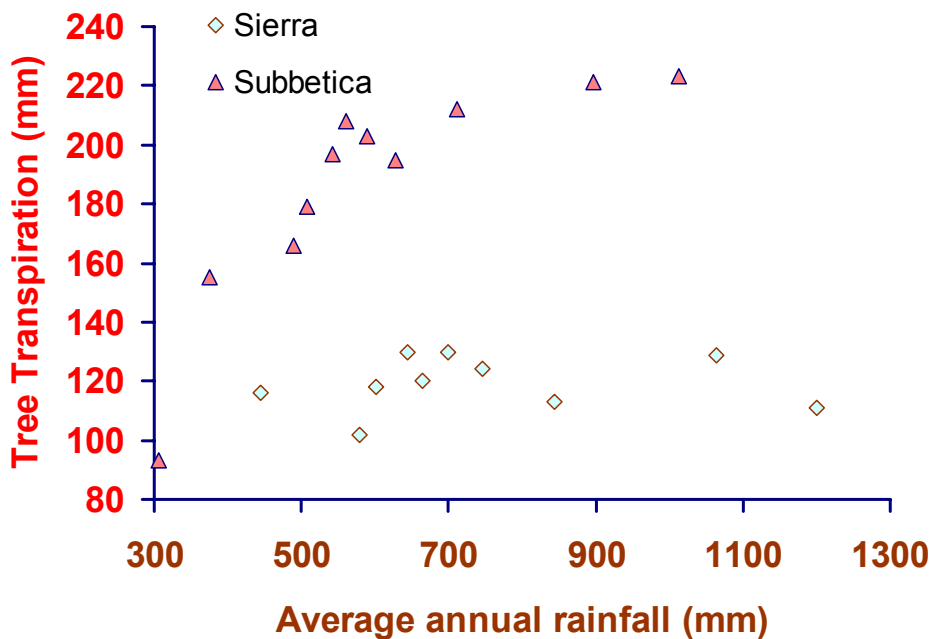


Figure 16: Comparison of tree transpiration, for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for Sierra and Subbetica.

Figure 17 compares the predicted tree transpiration for both management methods, cover crop and conventional tillage, in Sierra and Subbetica. The model predicts no losses in transpiration, or a slight increase in Subbetica, when shifting from conventional tillage into cover crop managed with the optimum killing dates for the cover crops presented in section 4.1. This is consistent with published reviews indicating no yield losses in olive orchards with cover crops properly managed (Gómez, 2005), and farmers perception in both study areas. It also suggests that the strategy of determining the killing date for a minimum difference with the alternative management (10 mm) keeping a water balance based on recorded rainfall at the farm (that most farmers do) and daily ET_o Penman-Monteith available in most agricultural areas in Andalusia free of charge through the WEB (<http://www.juntadeandalucia.es/agriculturaypesca>) is a appropriate strategy to minimize the risk of yield losses due to transpiration losses by cover crop competition.

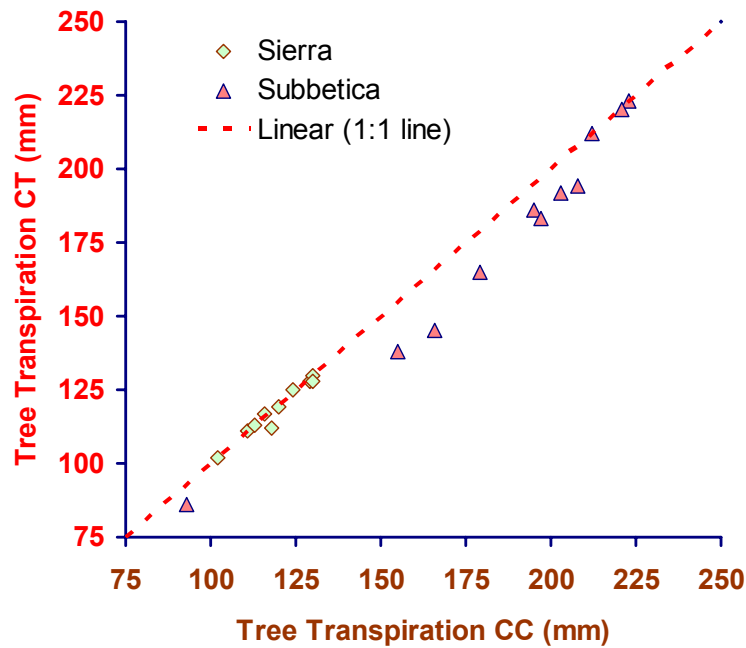


Figure 17: Comparison of tree transpiration in for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for Sierra and Subbetica.

Figure 18 shows differences in water losses trough drainage below the tree rooting depths at both areas. The larger losses in Sierra due to the reduced rooting depth are one of the reasons for differences in tree transpiration between area, Figure 16.

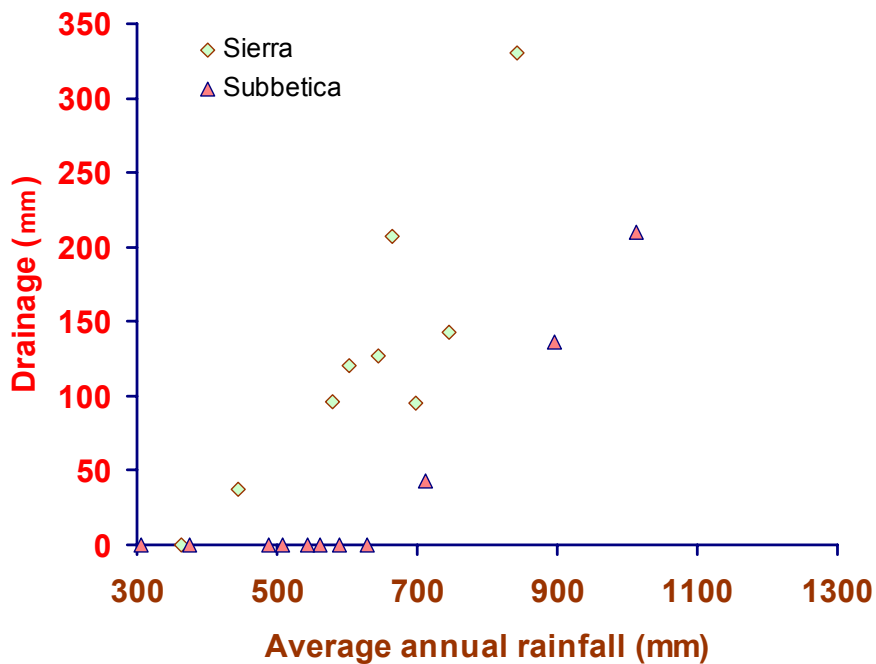


Figure 18: Comparison of drainage losses with optimum killing dates based on 10 mm maximum soil water differences. for Sierra and Subbetica

Figure 19 compares drainage losses at both areas between the cover crop and the conventional till management systems. It shows how drainage losses are larger in the cover crop system, explained by the reduction in runoff Figure 15, partially compensating the surplus of infiltrated water available for tree transpiration.

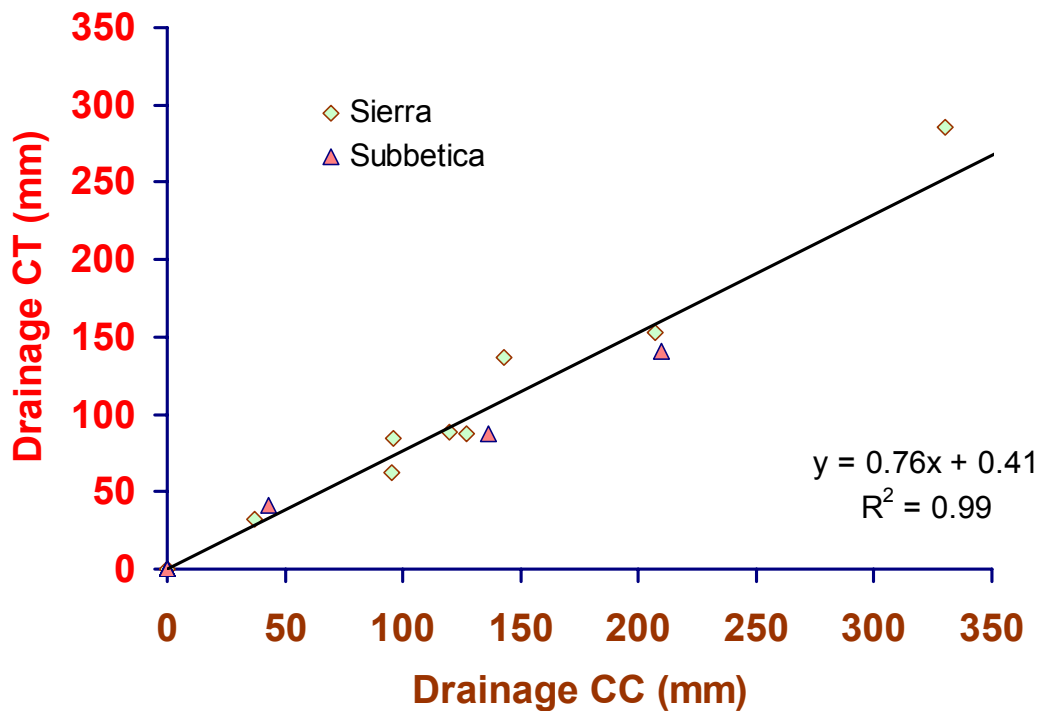


Figure 19: Comparison of drainage for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for Sierra and Subbetica.

Figure 20 shows the water transpired by the cover crop until the killing dates presented in section 4.1. Lower transpiration values correspond to for years with earlier killing dates. The water cost of growing a protective cover crop in the orchards study ranges between 50 and 100 mm that are provided by the increase in infiltration due to runoff reduction, Figure 15, and the reduction of the term of evaporation from bare soil, especially important in wet days, compared to the conventional till system.

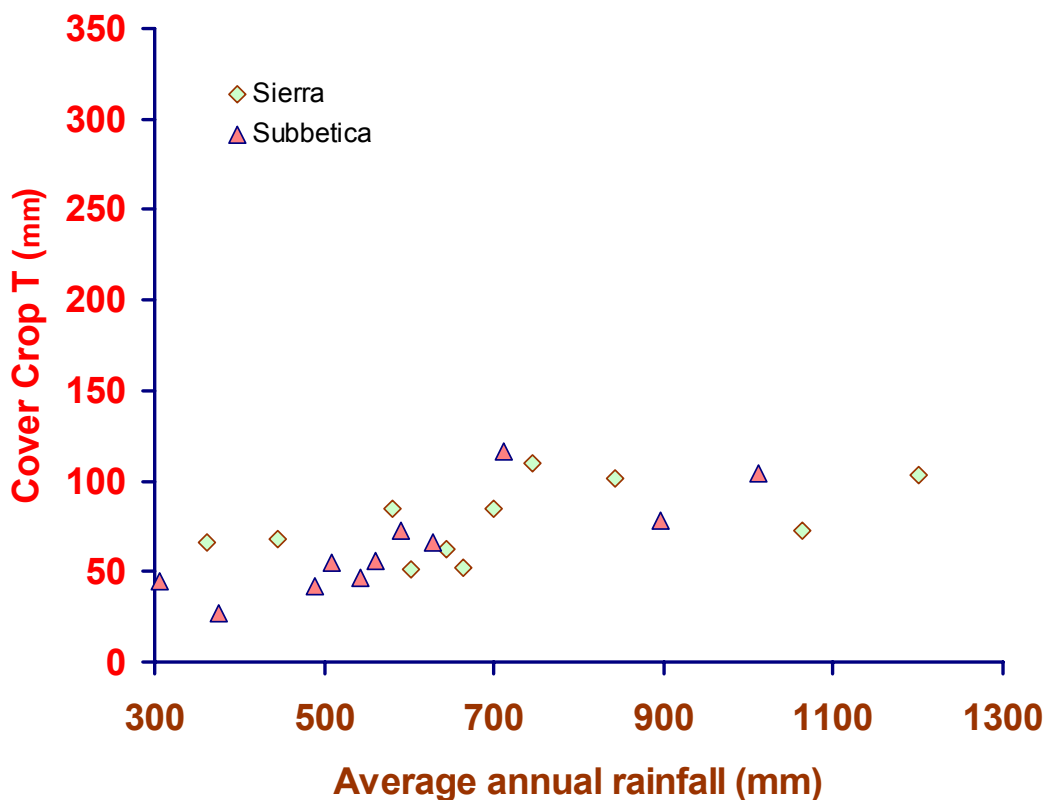


Figure 20: Comparison of cover crop transpiration, with optimum killing dates based on 10 mm maximum soil water differences, for Sierra and Subbetica.

4.4. Alternative strategies for cover crop management in Subbetica

The killing dates for the cover crop that will provide minimum risk of tree transpiration losses in Campiña, Figure 13, will be too early to allow the cover crop to provide enough biomass to protect the soil with residues until next fall, and complete its cycle to allow natural reseeding. In Sierra, the optimum killing dates are compatible with those two objectives.

One strategy to increase biomass production and cover crop seed production while keeping competition for water to a minimum is to delay the killing date until a suitable date for allowing the two objectives indicated before is found assuming a loss in olive

transpiration that can be estimated through OLIVCROP; the other to cover a smaller fraction of the orchard with a cover crop.

Figure 21 shows the differences in tree transpiration predicted for the model for Subbetica, for the same years simulated in sections 4.1 and 4.2, for several fixed killing dates.

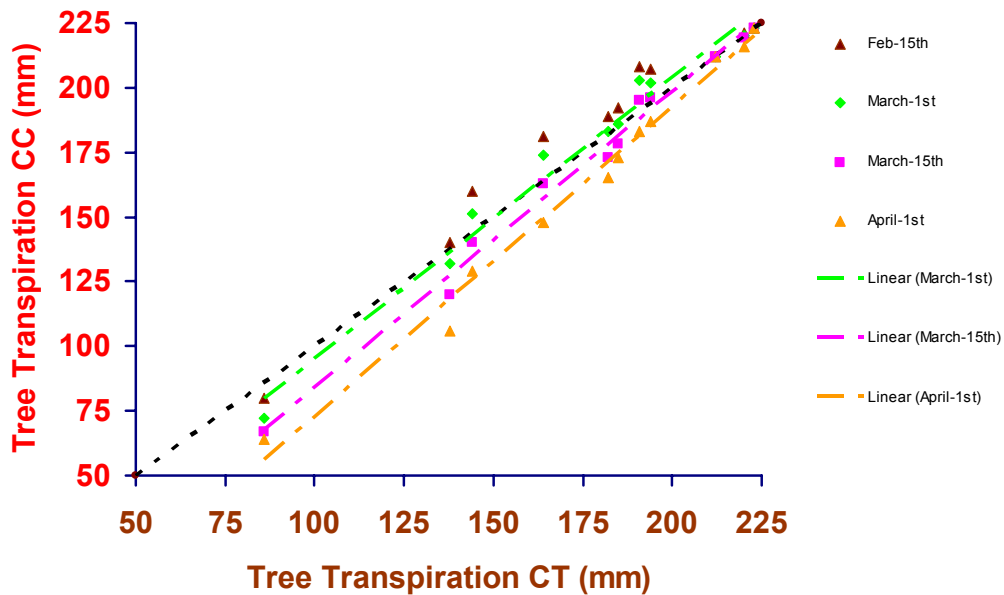


Figure 21: Comparison of olive tree transpiration in cover crop and conventional till for fixed killing dates Subbetica.

Results in Figure 21 indicate how for Subbetica, a killing date of March 15th, a date for which biomass production by a cover crop in the region can be enough to provide enough residues to protect soil until the next season (Pastor et al., 1999), differences in tree transpiration are minimal many years and moderate in the remaining ones.

Figure 22 indicates the same analysis but for Sierra, indicating how differences in olive transpiration are less sensitive to a delay in killing dates, not surprising given the optimum killing dates presented in Figure 13. Imposing a killing date in April 1st significant differences start to appear but not in many years. This indicates that there is space to increase biomass production by cover crop in this area delaying the killing date and using a fixed date, what could provide an additional protection and organic matter input to the soil, with a reduced risk of affecting yield.

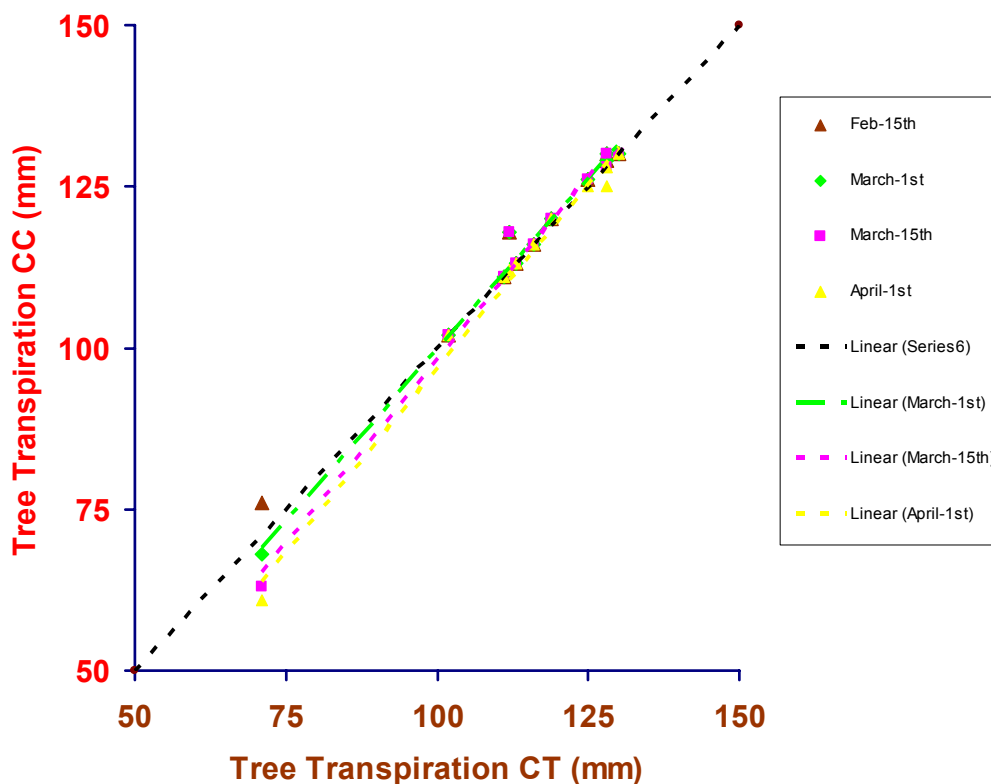


Figure 22: Comparison of olive tree transpiration in cover crop and conventional till for fixed killing dates in Sierra.

Other complementary strategy is a reduction in the extension of the cover crop. Although we do not recommend due to the reduction of the soil protection, Figure 8 gives an estimation of the gain in terms of number of days that we can delay the killing date of the cover crop without significantly increasing the risk of reducing tree transpiration compared to the alternative system based on conventional tillage.

4.5. Summary

Given the higher rainfall and soil conditions at Sierra the use of cover crops seems a reasonable strategy that can be achieved keeping a water balance based to determine an optimum killing date, that will vary from early to late March, or using a fixed killing date of mid March. That soil management will not have a significant impact in tree transpiration compared to a conventional management based on tillage, but will significantly decrease surface runoff. A significant fraction of this increase in

infiltration will drain below the rooting depth, going to aquifer recharge or subsurface flow. According to the model analysis the development of a cover crop without affecting tree transpiration under this rainfed conditions is possible by a combination of increase infiltration and reduction of the term of direct evaporation from bare soil.

In Subbetica, given the differences in climate, soil and orchard characteristics, the optimum killing dates, from late January to early March, are too premature to allow enough biomass production for the cover crop to provide enough residues to protect the soil until next fall. Under this circumstance our simulations suggest that delaying the killing date until mid March will mean only a minor reduction in tree transpiration. Simulations suggest that cover crop management will significantly decrease surface runoff. A significant fraction of this increase in infiltration will drain below the rooting depth only in wet years.

5. ANALYSIS OF GRANADA STUDY AREA

5.1. Material and methods

The study area in Granada-Jaén is divided in five SMOPS in function of the cultivation system (rainfed and irrigated), the intensification level of the plantation and the slope. The most important characteristics for each SMOPS are summarized in Table 7.

SMOP	Average Tree density	Slope (%)	Rainfed (R) or Irrigated (I)	Average production (kg/ha)
1	100	7-15	R	2500
2	120	7-15	I	4000
3	110	15-30	R	2000
4	120	> 30	R	1500
5	175	7-30	I	4500

Table 7: Description of SMOPS in Granada-Jaén study area

In order to apply the model OLIVCROP, these five SMOPS have been reduced to three: the rainfed ones, given the added difficulty of having to consider the data of the daily irrigation doses for the calculations. Also, according to the system used for the definition of the SMOPS throughout our study area exploitations with different slopes can be found and therefore they can be classified as different SMOPS. To be able to apply the model and to overcome the limitations imposed by the criteria used for the definition of the SMOPS, we have chosen a representative area for each one of them for which daily average data of precipitation and ET_0 is available. The areas are:

- SMOP 1 → Mancha Real (Jaén)
- SMOP 3 → Iznalloz (Granada)
- SMOP 4 → Pozo Alcón (Jaén)

From now on the area of Mancha Real will be known as ‘Campiña’, Iznalloz as ‘Los Montes’ and Pozo Alcón as ‘Sierra’.

The characteristics of the olive grove from each area are summarized in Table 8.

	Area Tree spacing (m)	Canopy diameter (m)	Rooting depth (m)
Campiña	10 x 10	6	2
Los Montes	9.5 x 9.5	5	1.5
Sierra	9 x 9	4	1.2

Table 8: Orchard characteristics simulated in the SMOPS analysis

The characteristics of the soil from each area are shown in Table 9.

	Soil texture	Hydrological class	Slope %
Campiña	Clay-loam	B	10
Los Montes	Loam	C	20
Sierra	Sandy-loam	C	30

Table 9: Soil characteristics simulated in the SMOPS analysis

In Table 10 the precipitation and ET_0 data determined by Penman-Monteith are shown. That data have been obtained from each place and for the last five agricultural years, finding both wet and dry years. This can give us an idea on the variability of the killing dates.

	Meteorological station	(mm)	Date				
			2000-2001	2001-2002	2002-2003	2003-2004	2004-2005
Campiña	Mancha Real (Jaen)	R	464.6	367.2	428.0	474.0	183.6
		ET_0	1502.0	1466.5	1465.3	1400.0	1565.0
Los Montes	Iznalloz (Granada)	R	795.0	597.8	641.6	707.4	188.0
		ET_0	1398.1	1346.3	1361.6	1287.6	1471.7
Sierra	Pozo Alcón (Jaen)	R	469.2	458.0	372.0	506.6	173.2
		ET_0	1292.2	1278.5	1292.5	1235.3	1378.0

Table 10: Meteorological station data

As can be seen in the table, the highest evapotranspiration rates correspond to the Campiña areas and the lowest ones to the Sierra because of the lower temperature. The precipitation is higher for the area of Los Montes being very similar for the other two areas.

For the three areas two alternatives of soil management are analyzed and compared: the traditional tillage and the cover crops. The width of the cover is supposed to be of 4 m for the three cases. The cover used for the areas Campiña and Los Montes is cereal, representing a percentage of soil covered of 85%. For Sierra area a cover of spontaneous vegetation is assumed, representing a percentage of soil covered of 90%.

The model is applied supposing that the establishment of the killing date is carried out when the difference in the soil water content among the cultivation with cover and the traditional tillage systems is smaller than 10 mm, to reduce to the maximum the possible losses in the yield of the olive grove.

5.2. Comparison of killing dates for cover crops in the areas

Figure 23 presents the optimum dates for killing the cover crops at the three study areas determined by OLIVCROP simulations.

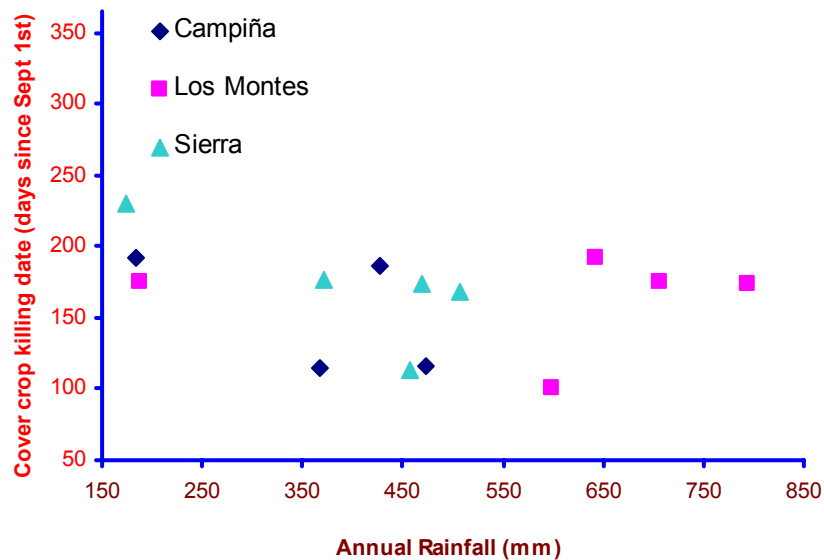


Figure 23: Optimum killing dates predicted for Campiña, Los Montes and Sierra for years with different rainfall in Granada-Jaen for a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system.

In the area of Campiña, the pattern proposes killing dates that go from final of December until middle of March, depending fundamentally on the date of emergence of the cover conditioned by the distribution of the first autumnal rains. For the area of Los Montes the killing date goes from first of December until middle of March, being the average killing date about final of February. In Sierra area, we find even more disparity in the proposed killing dates oscillating from final of December until middle of April, being the average date about final of February. This disparity in the proposed dates reflects the great influence that the annual rain as well as its distribution through the year has on the proposed killing date.

5.3. Hydrological fluxes in the areas.

Figure 24 shows how the annual runoff estimated by the pattern for the three areas with a soil management with cover, indicate losses of water for low runoff, never over 5%, what shows the protective effect of the soil that gives the cover.

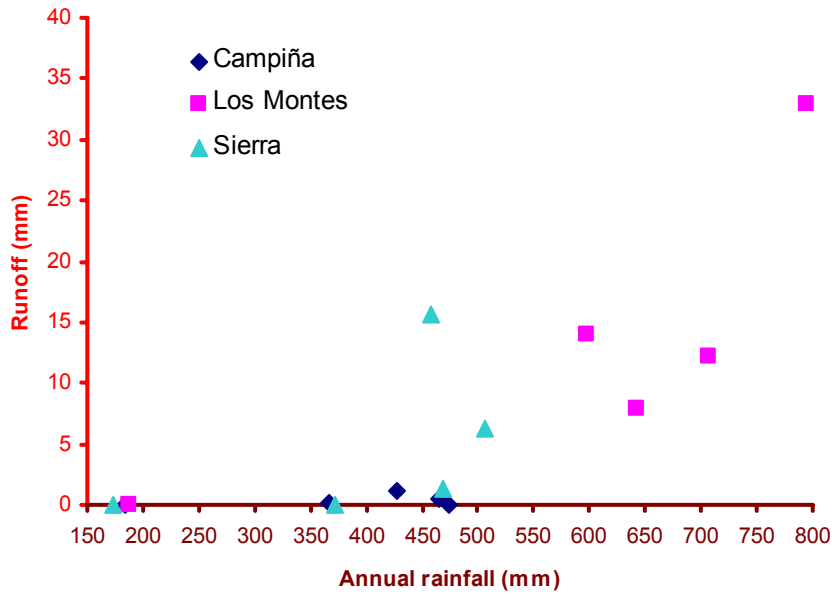


Figure 24: Annual runoff predicted for the areas for orchard with cover crop.

As it can be seen in Figure 25, the losses for runoff estimated by the pattern for the same area under a traditional tillage are much bigger, being this difference bigger as it increases the slope and the average rainfall. This reduction in the runoff that represents the establishment of the cover, is one of the reasons that justifies its use without involving the yield of the crop. This increment in the effective precipitation together with the reduction of the evaporation from the bare soil, cause an increase of the available water for the crop.

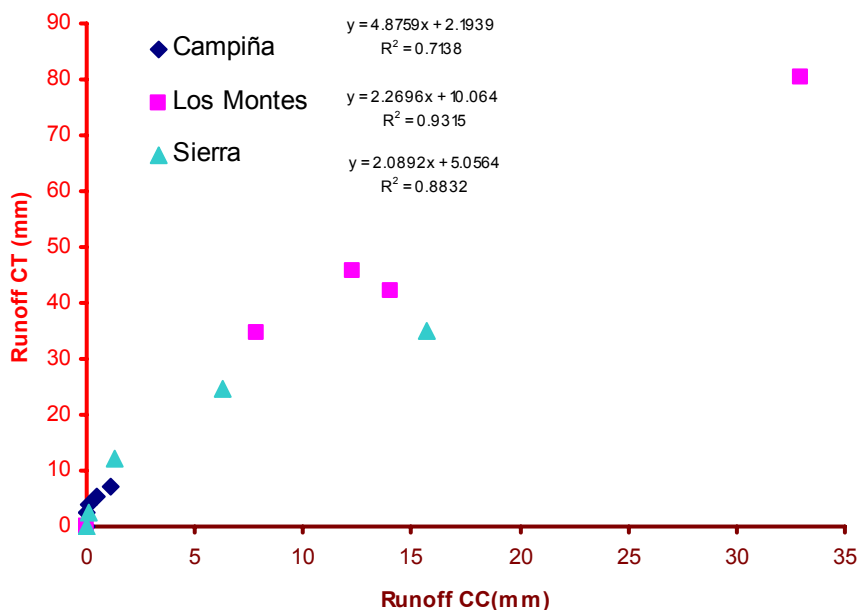


Figure 25: Comparison of annual runoff predicted for cover crop and conventional till in the areas.

Figure 26 shows the transpiration of the tree estimated for the three areas with a soil management with vegetable cover for different years, finding remarkable differences among the areas. It is also observed how it influences the annual precipitation in the rate of transpiration, existing remarkable differences between the abnormally dry years and the rest.

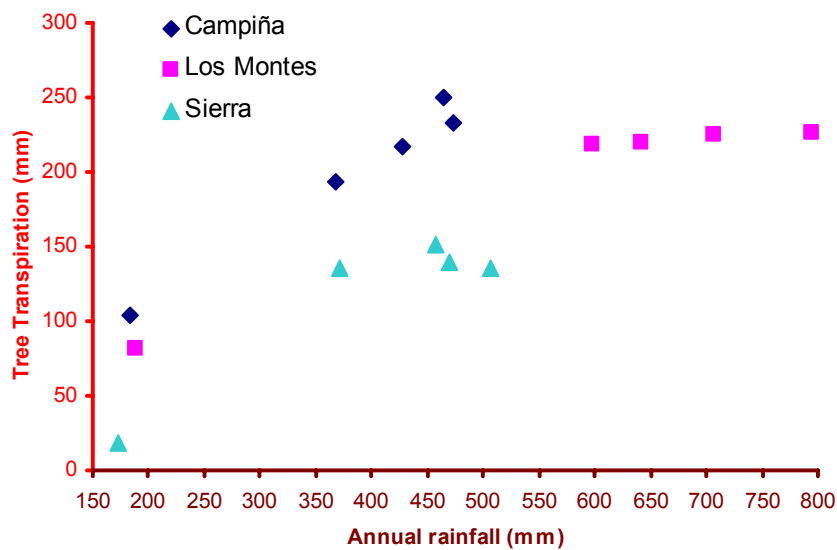


Figure 26: Tree transpiration for cover crop management with optimum killing dates based on 10 mm maximum soil water differences.

The Figure 27 compares the transpiration of the tree estimated for the two studied soil handlings, vegetable cover and conventional tillage, in Campiña, Los Montes and Sierra. The pattern predicts that important losses don't take place in the transpiration for the establishment of the cover whenever this is properly managed and as long as the killing date recommended by the pattern is followed, allowing us not to affect the yield of the crop.

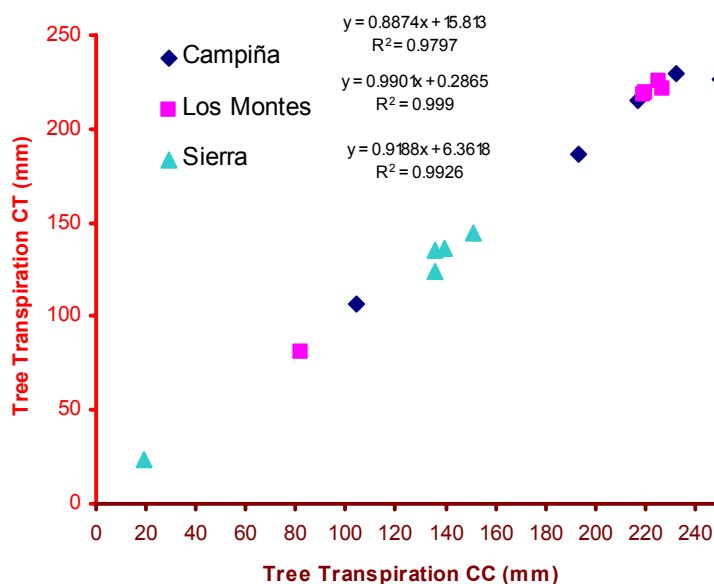


Figure 27: Comparison of tree transpiration, for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for Campiña, Los Montes y Sierra.

Figure 28 shows the differences in the water losses for deep drainage for the three areas. As it can be observed in the area of Campiña the drainage is null due fundamentally to the high rooting depth. In the areas of Los Montes and Sierra, it can be observed that the drainage is conditioned fundamentally by the annual precipitation.

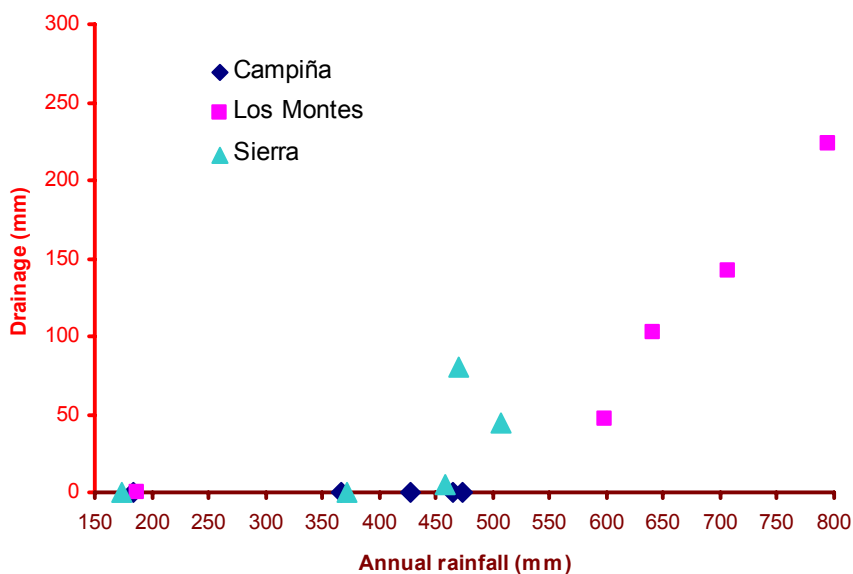


Figure 28: Comparison of drainage losses with optimum killing dates based on 10 mm maximum soil water differences, for Sierra and Subbetica

Figure 29 compares the losses for drainage in the three areas for both situations: the vegetable cover and the traditional tillage. In the area of Campiña the drainage is null for both soil treatments. For the other two areas it can be seen how the losses for drainage are bigger with the vegetable cover, due to the reduction of the runoff that represents its establishment.

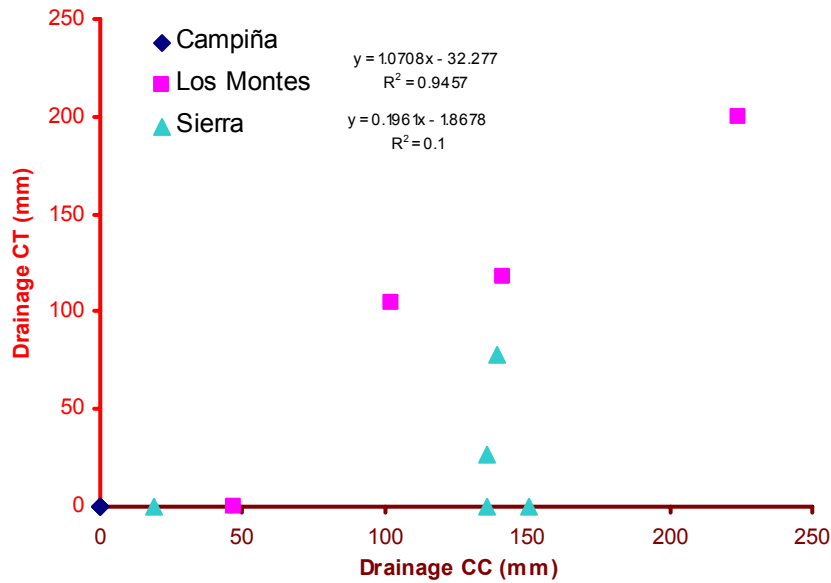


Figure 29: Comparison of drainage for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for Campiña, Los Montes and Sierra

Figure 30 shows the transpiration of water from the cover until the killing date estimated by the model, which has been shown in section 5.2. The lower values of transpiration correspond to years with early killing dates. The values of transpiration from the cover oscillate between 20 and 80 mm, (it can be considered as the cost of water that it should be assumed by the establishment of the cover).

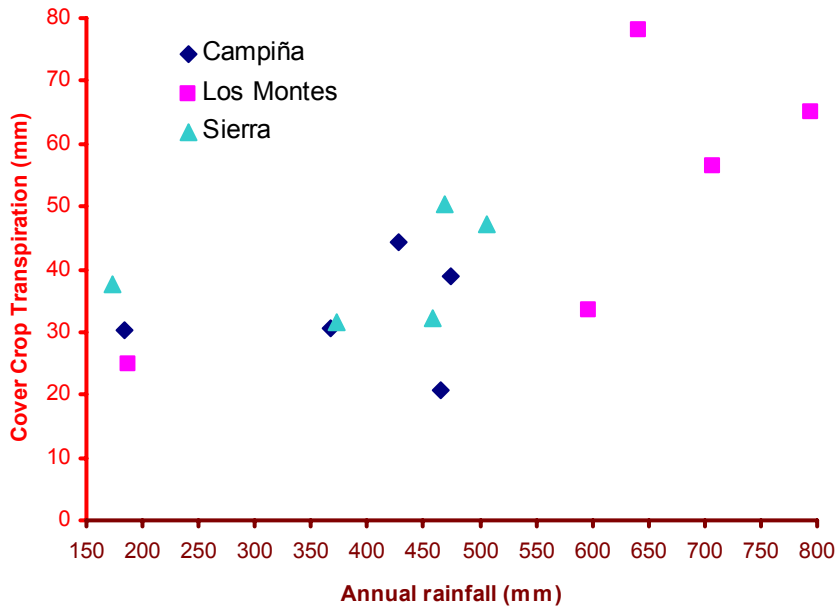


Figure 30: Comparison of cover crop transpiration, with optimum killing dates based on 10 mm maximum soil water differences, for Campiña, Los Montes y Sierra.

5.4. Alternative strategies for cover crop management in Granada-Jaen

The killing dates for the cover proposed by the model are those that suppose a lower risk of transpiration of the tree. However, as it can be observed in Figure 23 these dates appear very early, so that it would not guarantee a correct development of the cover to protect the soil against erosion. And in Sierra area a too early sowing date of the spontaneous vegetation cover would not guarantee the sowing for the next season. A strategy to increase the biomass and seed production for the cover would be to retard the killing date. This supposes a decrease in the transpiration of the tree that can be estimated by means of this model. Another strategy to guarantee the production of seeds for the spontaneous vegetation cover would be to leave a small cover fringe that guarantees the auto sowing. The Figure 31 shows the differences in the transpiration of the tree estimated by the model for Campiña, for the same years simulated in the previous sections, by fixing different killing dates. It can be noticed in Campiña area that the most appropriate killing date is March the 1st because the differences in the transpiration of the tree are minimum among the two soil treatments and at the same

time a correct development of the cover is possible in order to guarantee the protection of the soil.

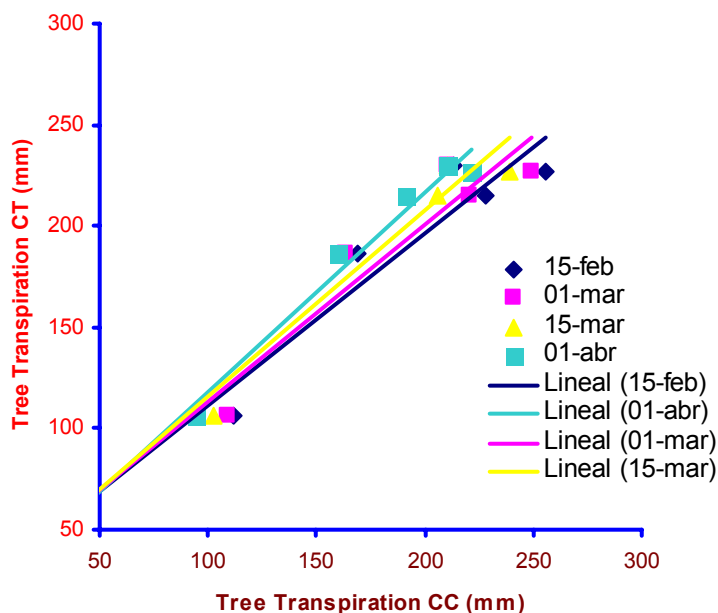


Figure 31: Comparison of olive tree transpiration in cover crop and conventional till for fixed killing dates Campiña

Figure 32 shows how the killing date of March the 1st is the most appropriate for Los Montes, achieving both objectives: protecting the soil and not committing the crop yields.

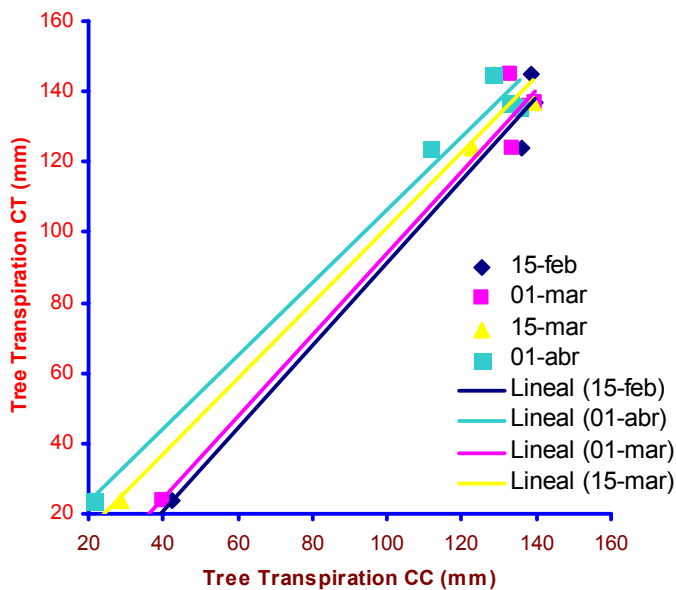


Figure 32: Comparison of olive tree transpiration in cover crop and conventional till for fixed killing dates Los Montes.

In figure 33 it can be noticed how the optimum killing date is March the 1st as well for Sierra area.

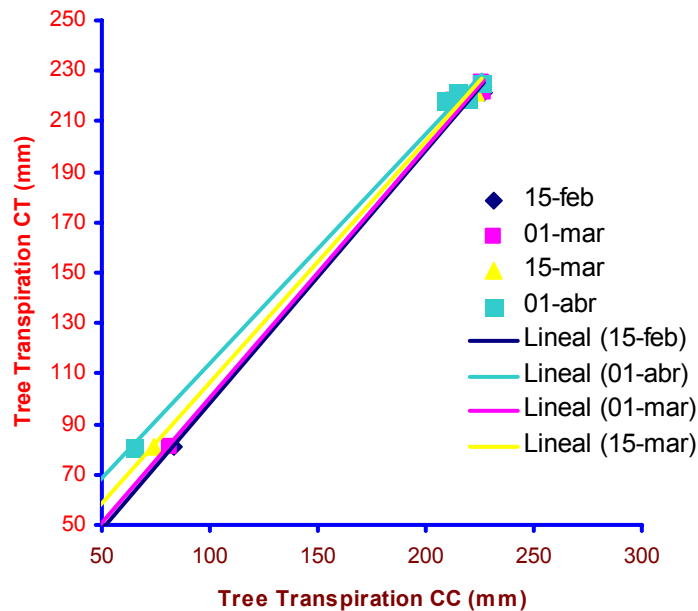


Figure 33: Comparison of olive tree transpiration in cover crop and conventional till for fixed killing dates Sierra

5.5. Summary

Given the conditions of irregular rainfall within the study area, both among the different years and the distribution of the precipitations through the year, the model offers a great disparity in the best killing dates proposed that go from principles of December until the middle of April. The very early killing dates don't guarantee a correct development of the cover to guarantee the protection of the soil. A solution would be to fix a killing date that has been considered as good (March the 1st) for the three areas that allows to reach an appropriate development of the cover and so decreasing the risk of yield losses in the crop.

The model shows how when the proposed killing date is applied or when the killing date is fixed, the differences in the transpiration of the tree, between the utilization of cover crops and the traditional tillage are reduced, and consequently the risk of

reduction of the yield is minimum. It is also observed how the establishment of the cover supposes an important reduction of the runoff because being favoured the infiltration is favoured by that and the evaporation from the bare soil decreases.

6. ANALYSIS OF CRETE STUDY AREA

6.1. Material and methods

The Crete study area deal cover the western part of the island of Crete, and the olive orchard in that area four SMOPS fully describe in Metzidakis (2004) and Xiloiannis et al. (2004). The key SMOPS characteristics are summarized in Table 11.

#	SMOP Types	Tree density Tree/ha	Average Yield Kg/ha	Description
1	Traditional, extensive.	50-80	1200-2500	Traditional extensive plantations on steep slopes. Usually terraced.
2	Traditional, intensive	70-200	2500-4500	Traditional plantations on steep slopes, more intensive than those in SMOP 1. Usually terraced.
3	Modern, intensive.	200-300	5000-8000	Modern intensive plantations.
4	Organic.	50-300	3000-7000	Organic olive orchard plantations.

Table 11: Brief description of SMOPS in Crete study area

These four SMOPS can be simplified in three, since the organic production system can be present at any of the three first SMOPS described in Table 11. For each of these three areas several types of olive orchards were simulated based on the orchard description presented in Metzidakis (2004) and Xiloyannis et al. (2004) and summarized in Table 12, result of a combination fo different slope, soil and orchard characteristics.

Scenario	Tree spacing (m)	Canopy diameter (m)	Rooting depth (m)	Slope (%)	Soil texture
1-SMOP1a	12x12	7	1.2	30	Clay-loam
2-SMOP1b	12x12	7	1.2	30	Loam
3-SMOP1c	12x12	7	1.8	1	Clay-loam
4-SMOP1d	12x12	7	1.8	1	Loam
5-SMOP2a	9x9	6	1.2	15	Clay-loam
6-SMOP2b	9x9	6	1.2	15	Loam
7-SMOP2c	9x9	6	1.8	1	Clay-loam
8-SMOP2d	9x9	6	1.8	1	Loam
9-SMOP3a	7x7	5	1.2	15	Clay-loam
10-SMOP3b	7x7	5	1.2	15	Loam
11-SMOP3c	7x7	5	1.8	1	Clay-loam
12-SMOP3d	7x7	5	1.8	1	Loam

Table 12: Orchard characteristics simulated in the SMOPS analysis

In all the scenarios and analysis two different soil management options were evaluated: conventional till, and cover crop. Scenarios with slope 1% represent terraced orchards. In the cover crop management the cover crop strip width was 4-m in all the scenarios, except in SMOP1 where it was 6 m, consisting in natural vegetation. OILCROP model was run with the option of determining the date for cover crop killing when differences in soil water content between the cover crop and the alternative conventional till system were larger than 10 mm.

For all the scenarios a single average year was simulated (Metzidakis personal communication). The simulated average year had an annual rainfall of 594 mm and $ET_{Op_{an_evaporation}}$ of 1158 mm.

6.2. Evaluation of killing dates for cover crops in different scenarios

Figure 34 presents the optimum dates for killing the cover crops for an average year and the different scenarios indicated in Table 12 determined by OLIVCROP simulations.

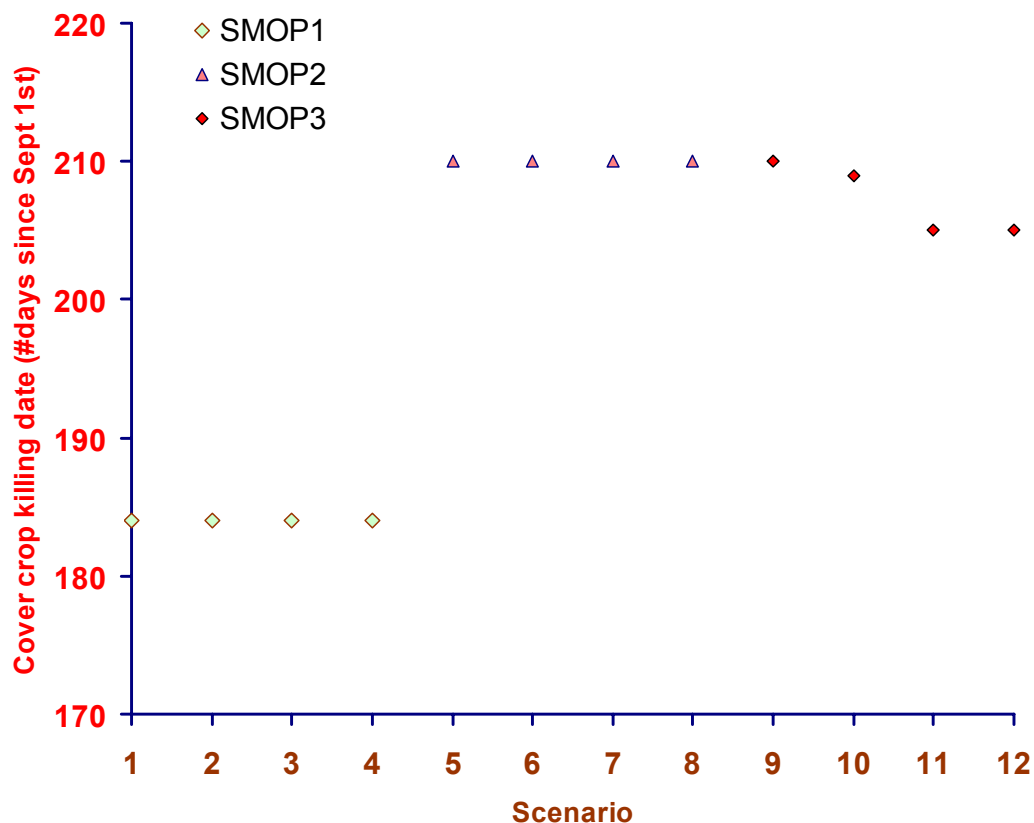


Figure 34: Optimum killing dates predicted for the different scenarios in Crete for a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

Results in Figure 34 indicate how the optimum killing dates for an average year will range from early March to late March depending on the orchard conditions. A more detailed study, in the same fashion than those presented for Cordoba and Granada, would have been presented if more weather information would have been available. With the limitations presented by the scarcity of weather data, results in Figure 34 suggests optimum killing dates similar to those presented in other Mediterranean olive production areas, previously presented. Given the large variability in rainfall within

Crete, extrapolation of these optimum killing dates within the other areas in Crete with different average rainfall should not be made before previous analysis with OLIVCROP.

6.3. Hydrological fluxes in the different scenarios.

Figure 35 shows the predicted annual runoff for the different scenarios and cover crop management indicating low runoff losses for the terraces scenarios, and relatively high never for the unterraced scenarios in SMOPS 1 and 2 with steeper slopes and reduced ground cover.

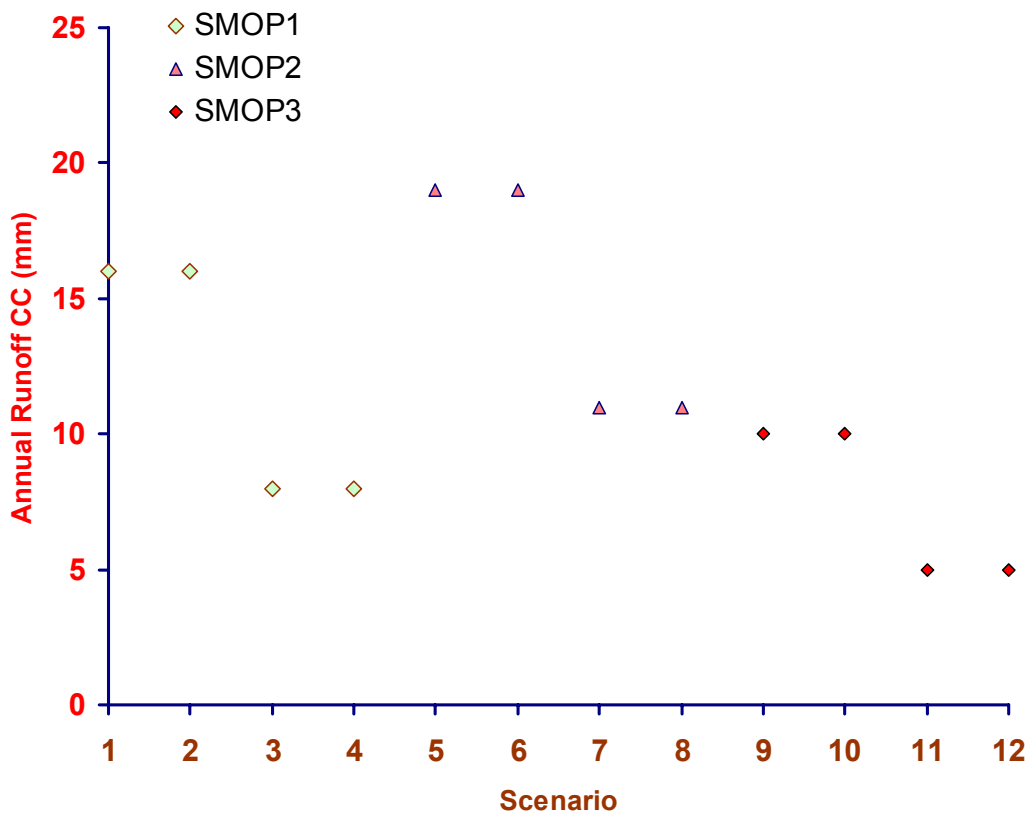


Figure 35: Annual runoff predicted for both areas for orchard with cover crop.

Results presented in Figure 36 indicate the reduction in runoff predicted by OLIVCROP in the different scenarios when a cover crop is used instead of conventional tillage.

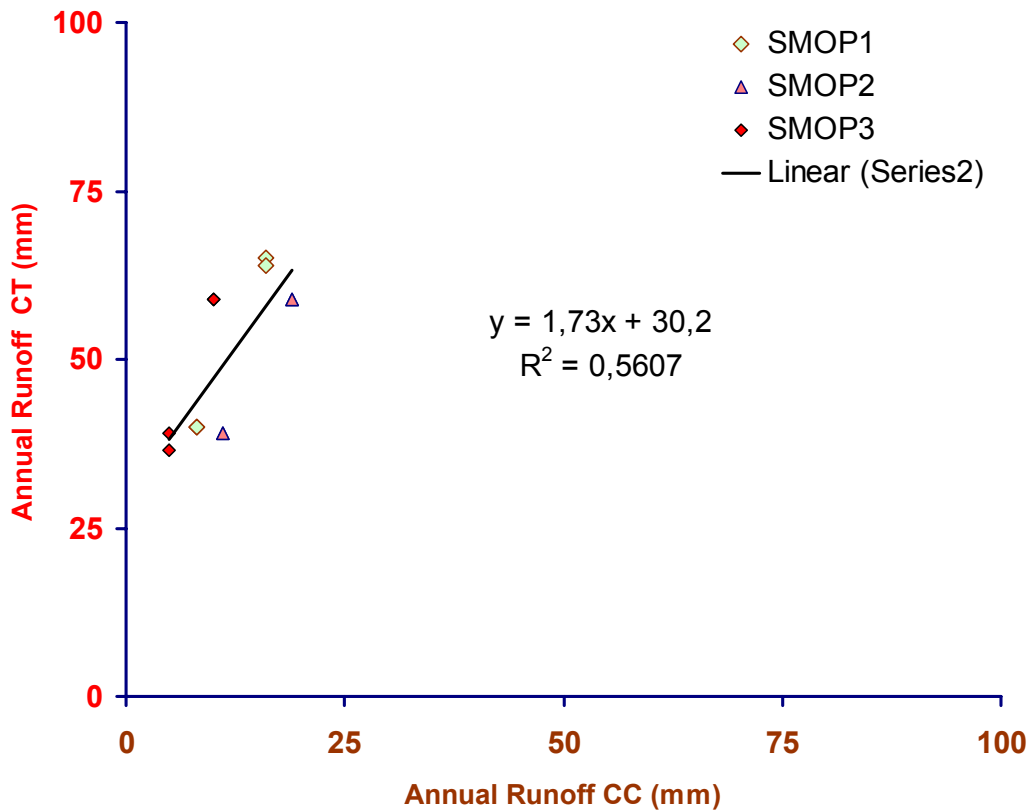


Figure 36: Comparison of annual runoff predicted for cover crop and conventional till in the different scenarios.

Figure 36 presents the annual transpiration of the olive trees for the different scenarios for both conventionally tilled and cover crop with optimum killing dates, indicating no reduction of tree transpiration compared to the traditional systems, and the broad range in tree transpiration due to different orchard characteristics even for the same annual rainfall.

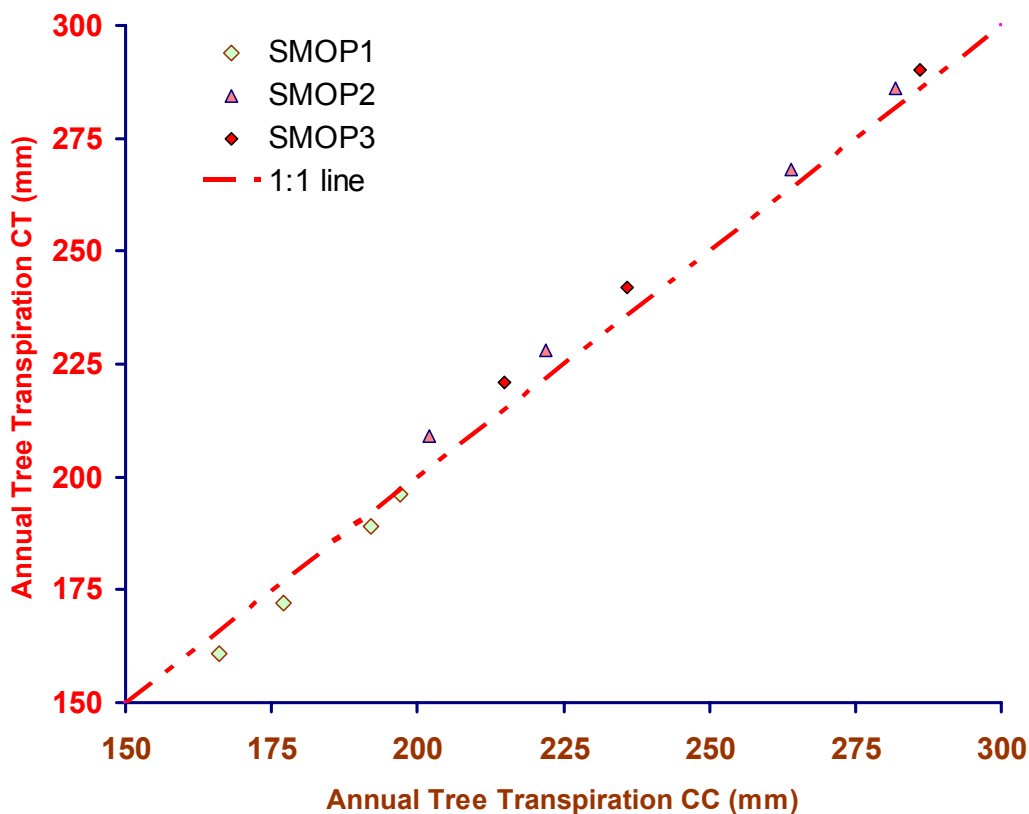


Figure 37: Comparison of tree transpiration, for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

Olive transpiration is larger in the scenarios simulating a terraced orchard compared to those located on a steep slope. This is a consequence of the reduced rooting depth in the latter what affects water losses by drainage below the rooting depth, shallower on unterraced slopes. Figures 38 and 39 show the absolute values of drainage and the comparison between cover crop and conventionally tilled managed for the different scenarios.

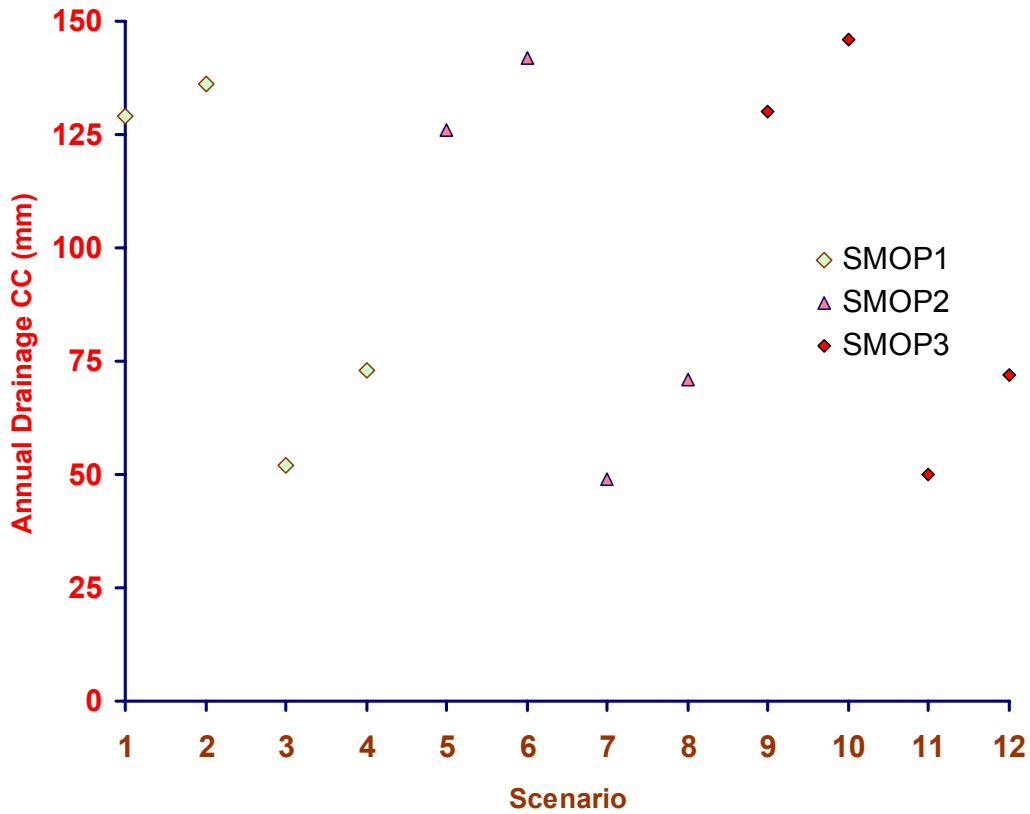


Figure 38: Comparison of drainage losses with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios

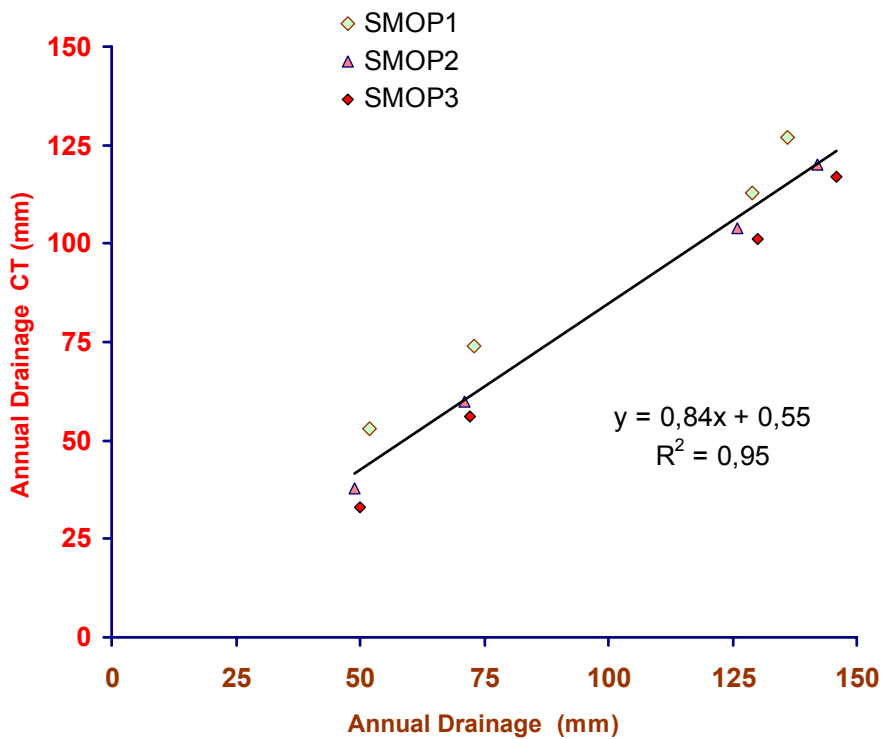


Figure 39: Comparison of drainage for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

Figure 40 shows the water transpired by the cover crop until the killing dates presented in section 6.2. for an average year in Crete. They seem to be in the range of those presented for other locations in the Mediterranean with similar climate, see sections 4 and 5. The water cost of growing a protective cover crop in the orchards studied ranges between 75 and 85 mm that are provided by the increase in infiltration due to runoff reduction, Figure 36, and the reduction of the term of evaporation from bare soil, especially important in wet days, compared to the conventional till system.

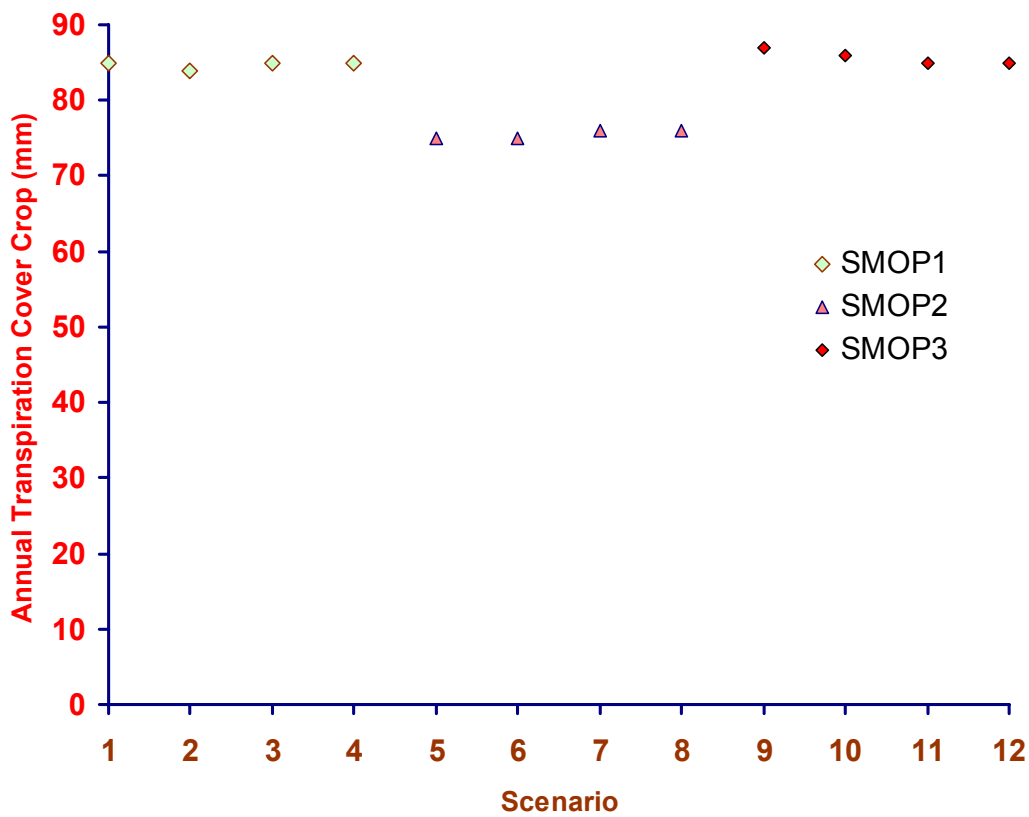


Figure 40: Comparison of cover crop transpiration, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

6.4. Alternative strategies for cover crop management.

The killing dates for the cover crop that will provide minimum risk of tree transpiration losses in some scenarios, Figure 34, will be too early to allow the cover crop to provide enough biomass to protect the soil with residues until next fall, and complete its cycle to

allow natural reseeding. One strategy to increase biomass production and cover crop seed production while keeping competition for water to a minimum is to delay the killing date until a suitable date for allowing the two objectives indicated before is found assuming a loss in olive transpiration that can be estimated through OLIVCROP; the other to cover a smaller fraction of the orchard with a cover crop. The evaluation of such the effect on tree transpiration of the use of a fixed date for killing the cover crop in late winter, March 15th, is presented in Figure 41. It indicates how the predicted effect on olive tree transpiration is very small. Figure 41 suggests that the use of a fixed killing date of March 15th for the regions in Crete with similar climate and characteristics to those considered in our analysis seem reasonable.

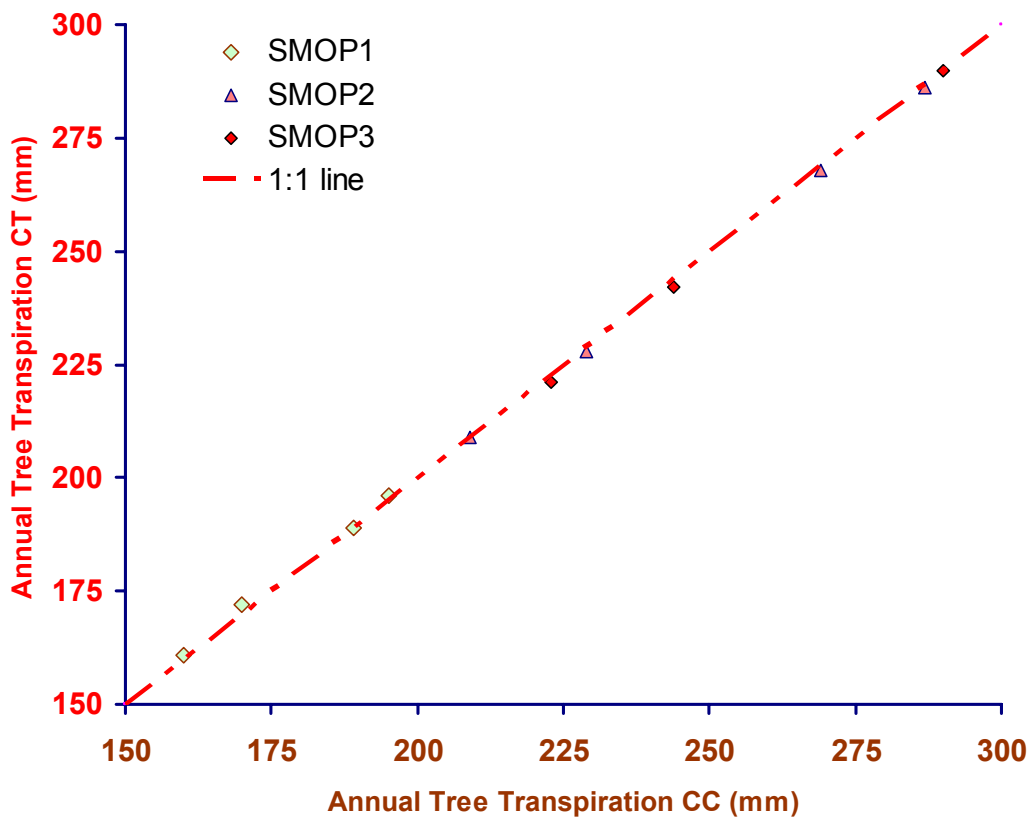


Figure 39: Comparison of olive tree transpiration in cover crop and conventional till for killing date March 15th.

6.5. Summary

Given the limited weather data available for the simulation analysis in Western Crete, our results can only be preliminary and limited to the specific conditions simulated.

With this consideration made, our results suggests that it is feasible a cover crop management of the olive orchards that with a killing dated of the cover crop in Mid March will insure no limitation of the olive tree compared to the conventional tillage management. At the same time this management will provide significant benefits in terms of reduction of runoff losses compared to conventional till, although these losses will remain high in the steepest areas. A significant fraction of this increase in infiltration will drain below the rooting depth, going to aquifer recharge or subsurface flow.

7. ANALYSIS OF BASILICATA STUDY AREA

7.1. Material and methods

The Basilicata study area deal cover part of Souther Italy, and the olive orchards in that area are fully describe in Metzidakis (2004) and Xiloiannis et al. (2004).The key SMOPS characteristics are summarized in Table 13.

#	SMOP Types	Tree density Tree/ha	Average Yield Kg/ha	Description
1	Traditional, extensive.	70-150	Max 2000	Traditional extensive rainfed plantations.
2	Traditional, intensive	>200	2500-4500	Traditional plantations more intensive than those in SMOP 1.
3	Modern, extensive.	100-150	2000-3500	Modern extensive plantations.
4	Modern intensive	>200	4500-8000	Modern intensive plantations
5	Environmentally respectfull.	Variable	2000-3000	Olive orchard with integrated or organic management.

Table 13: Brief description of SMOPS in Basilicata study area

These four SMOPS can be simplified in three, since the organic production system can be present at any of the three first SMOPS described in Table 11. For each of these three areas several types of olive orchards were simulated based on the orchard description presented in Metzidakis (2004) and Xiloyannis et al. (2004) and summarized in Table 14.

Scenario	Tree spacing (m)	Canopy diameter (m)	Rooting depth (m)	Slope (%)	Soil texture
SMOP1	10x10	5	1.2	20	Clay-loam
SMOP2	6x6	3.7	1.2	20	Clay-loam
SMOP3	10x10	5	1.6	10	Clay-loam
SMOP4	6x6	4.5	1.6	5	Clay-loam

Table 14: Orchard characteristics simulated in the SMOPS analysis

In all the scenarios and analysis two different soil management options were evaluated: conventional till, and cover crop. In the cover crop management the cover crop strip width was 4-m in all the scenarios, except in SMOP1 where it was 6 m, consisting of natural vegetation. OILCROP model was run with the option of determining the date for cover crop killing when differences in soil water content between the cover crop and the alternative conventional till system were larger than 10 mm.

For all the scenarios five years were simulated from weather data corresponding to Bari (average annual rainfall 482 mm and average annual $ET_{O_{Hargreaves}}$ 1482 mm).

7.2. Evaluation of killing dates for cover crops in different scenarios

Figure 42 presents the optimum dates for killing the cover crops for several years and the different scenarios indicated in Table 14 determined by OLIVCROP simulations.

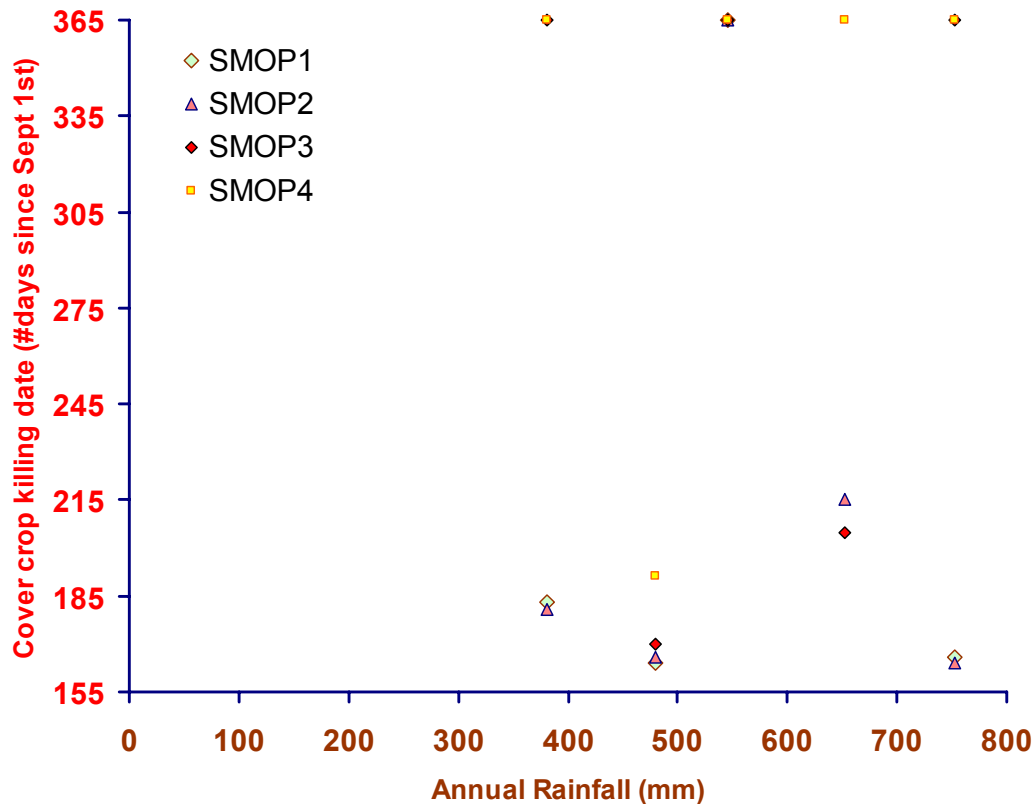


Figure 42: Optimum killing dates predicted for the different scenarios in Crete for a maximum difference of 10 mm in soil water content between the cover crop system and the alternative conventional till system. Killing date 365 means no need to kill the cover crop.

Results in Figure 42 indicate how the optimum killing dates varies for the same location depending on the amount and timing of the precipitation. They range from early February up to no need for killing before the weeds naturally die. There are differences among the different SMOPS.

7.3. Hydrological fluxes in the different scenarios.

Figure 43 shows the predicted annual runoff for the different scenarios and cover crop management indicating low runoff losses for most of the years and SMOPS. Only in rainy years the steepest SMOPS with reduced tree cover, 1 and 3, present high runoff losses. Results in Figure 44 quantify the reduction in runoff losses due to the use of a cover crop in the SMOPS studied.

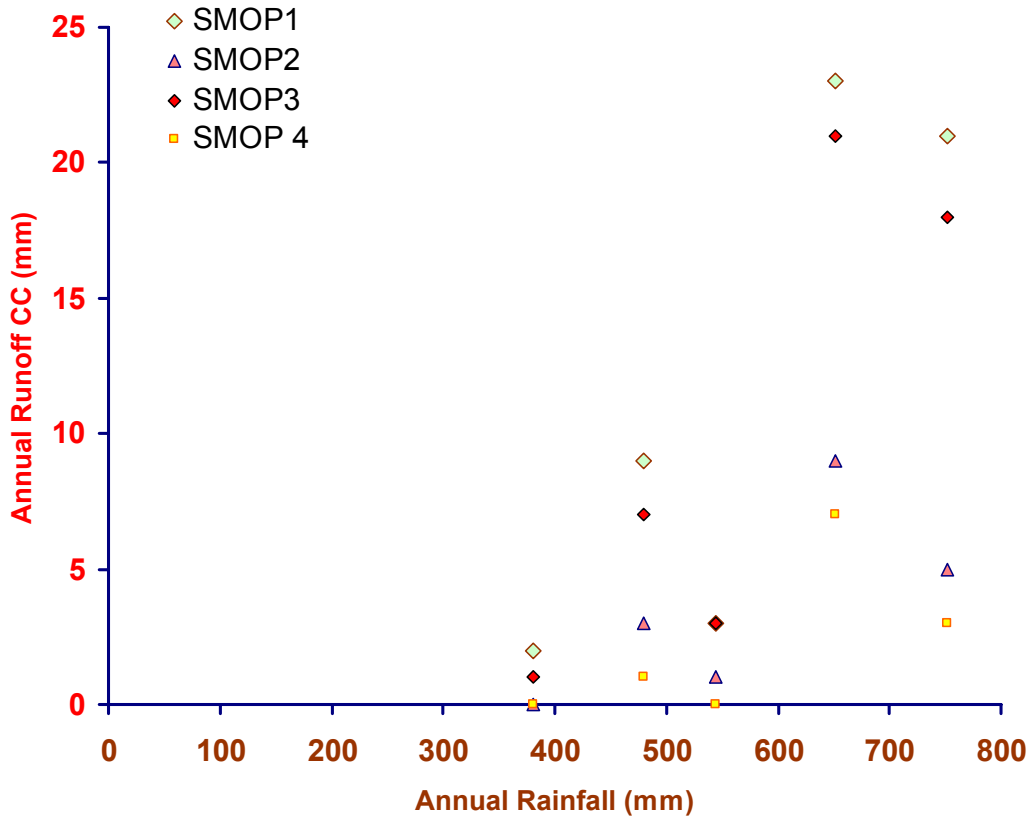


Figure 43: Annual runoff predicted for both areas for orchard with cover crop.

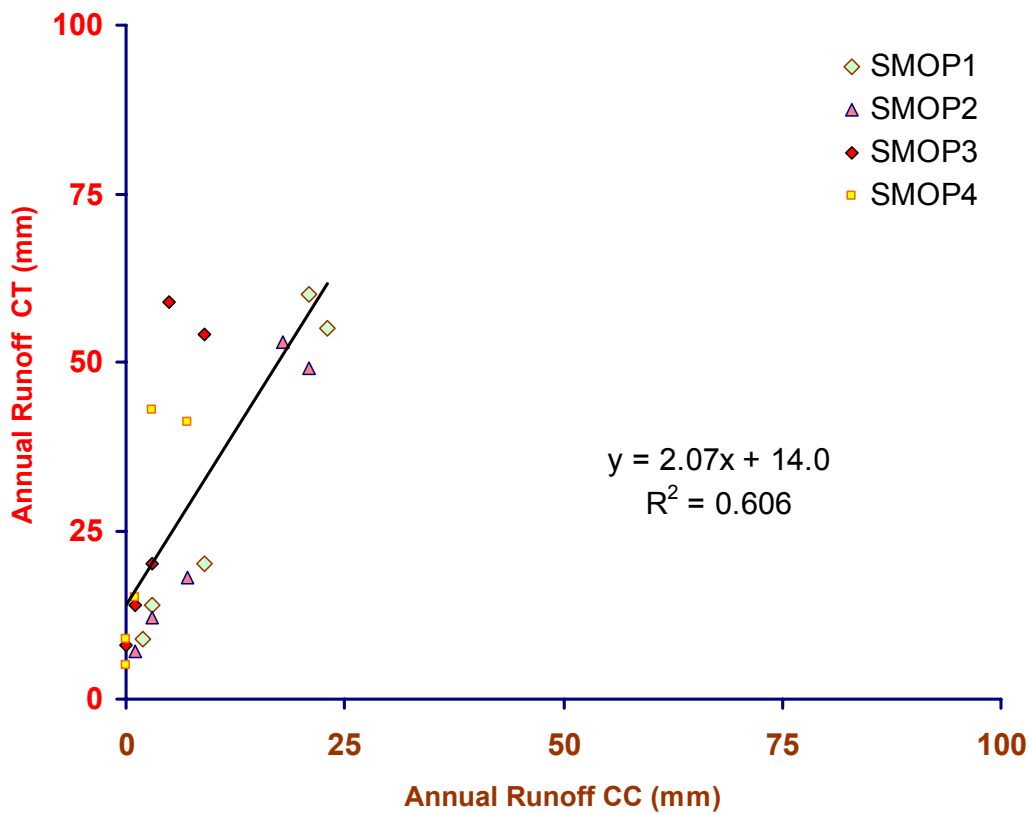


Figure 44: Comparison of annual runoff predicted for cover crop and conventional till in the different scenarios.

Figure 45 presents the annual transpiration of the olive trees for the different scenarios for both conventionally tilled and cover crop with optimum killing dates, indicating no reduction of tree transpiration compared to the traditional systems.

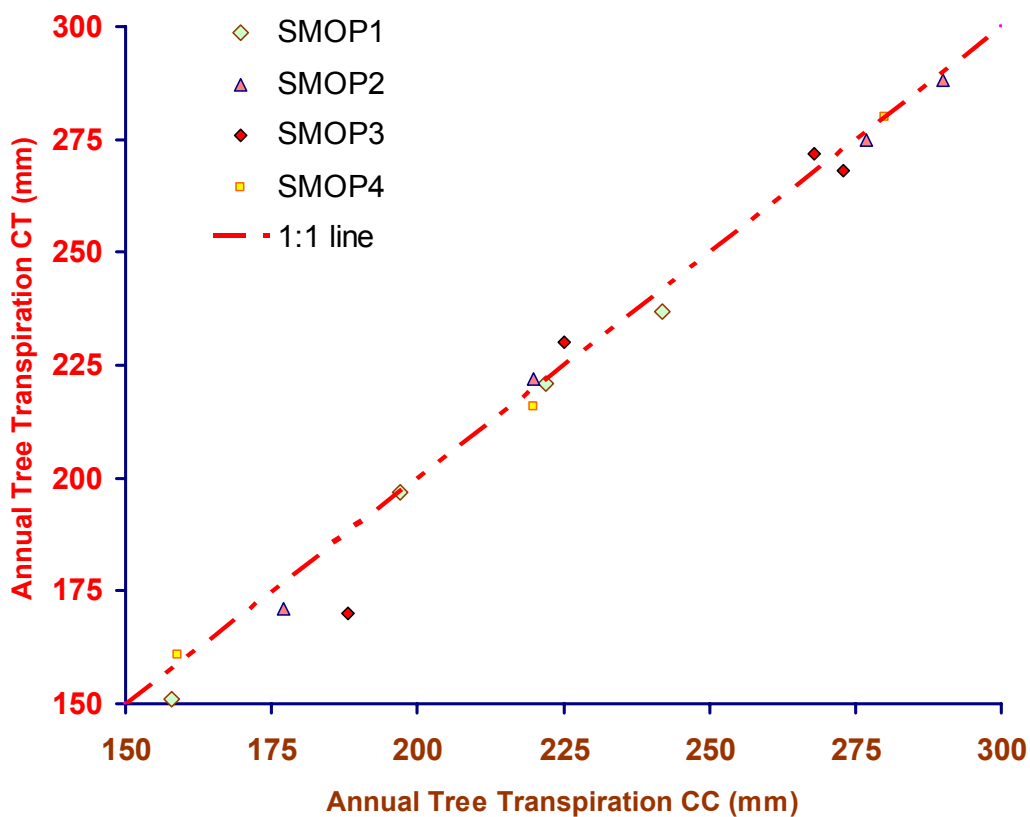


Figure 45: Comparison of tree transpiration, for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

Figures 46 and 47 show the absolute values of drainage and the comparison between cover crop and conventionally tilled managed for the different scenarios. Figure 44 indicates how drainage losses are significant only in wet years, and Figure 45 how these area larger in the cover crop management due to higher infiltration of rainfall water.

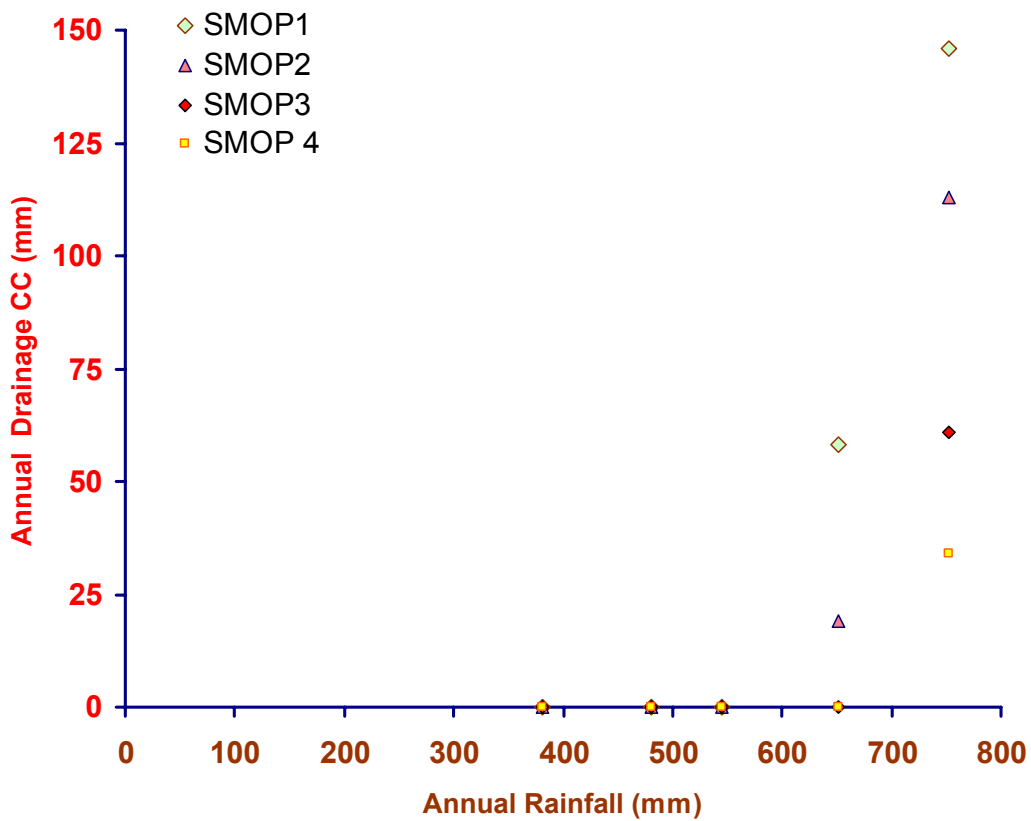


Figure 46: Comparison of drainage losses with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios

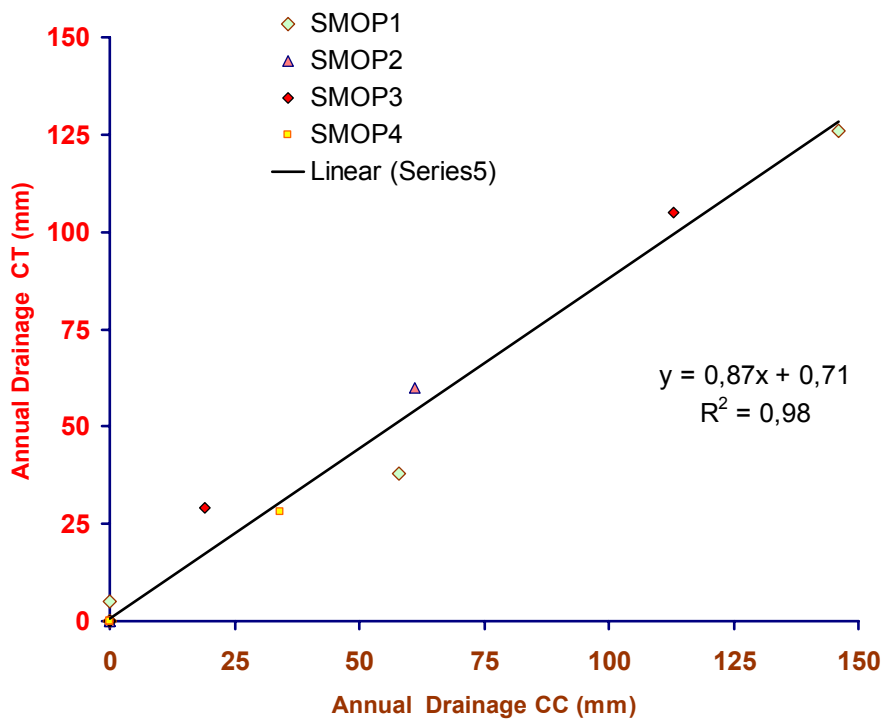


Figure 47: Comparison of drainage for cover crop management and conventional tillage, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

Figure 48 shows the water transpired by the cover crop until the killing dates presented in section 7.2. They seem to be in the range of those presented for other locations in the Mediterranean with similar climate, see sections 4, 5 and 6. The water cost of growing a protective cover crop in the orchards studied ranges between 40 and 100 mm that are provided by the increase in infiltration due to runoff reduction, Figure 44, and the reduction of the term of evaporation from bare soil, especially important in wet days, compared to the conventional till system.

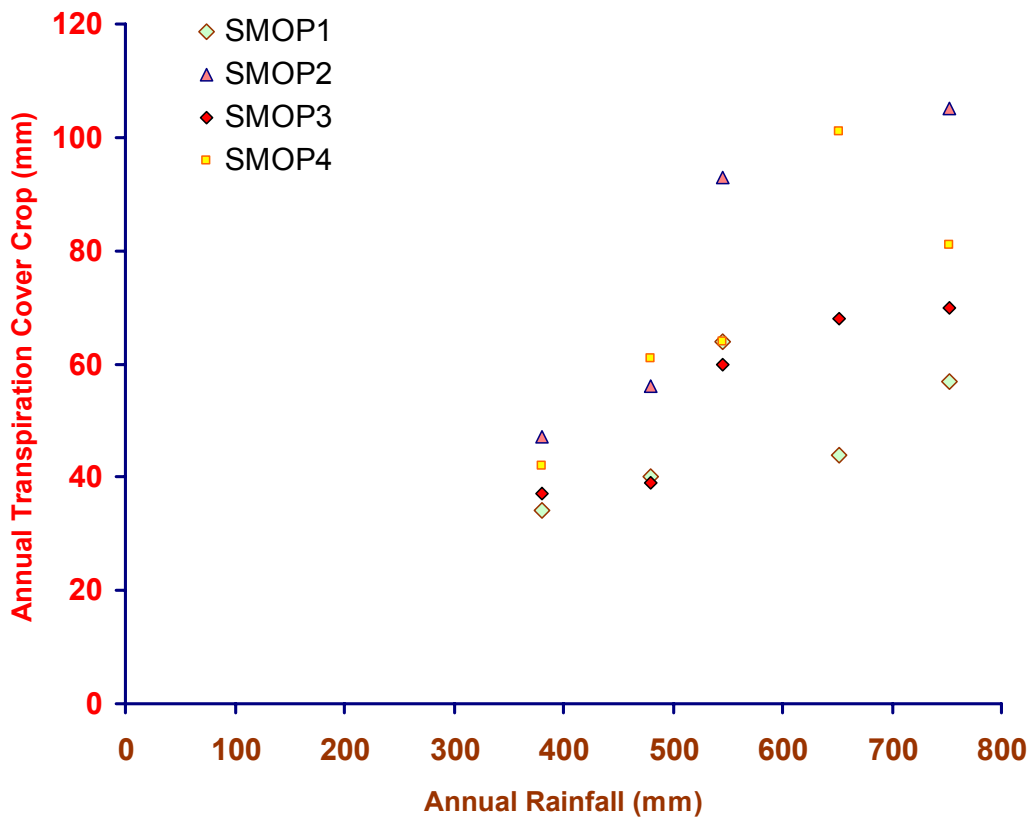


Figure 48: Comparison of cover crop transpiration, with optimum killing dates based on 10 mm maximum soil water differences, for different scenarios.

7.4. Alternative strategies for cover crop management.

The killing dates for the cover crop that will provide minimum risk of tree transpiration losses in some scenarios, Figure 42, will be too early to allow the cover crop to provide

enough biomass to protect the soil with residues until next fall, and complete its cycle to allow natural reseeding. One strategy to increase biomass production and cover crop seed production while keeping competition for water to a minimum is to delay the killing date until a suitable date for allowing the two objectives indicated before is found assuming a loss in olive transpiration that can be estimated through OLIVCROP; the other to cover an smaller fraction of the orchard with a cover crop. The evaluation of such the effect on tree transpiration of the use of an fixed date for killing the cover crop in late winter, March 15th, is presented in Figure 49. It indicates how the predicted effect on olive tree transpiration is very small. Figure 49 suggests that the use of a fixed

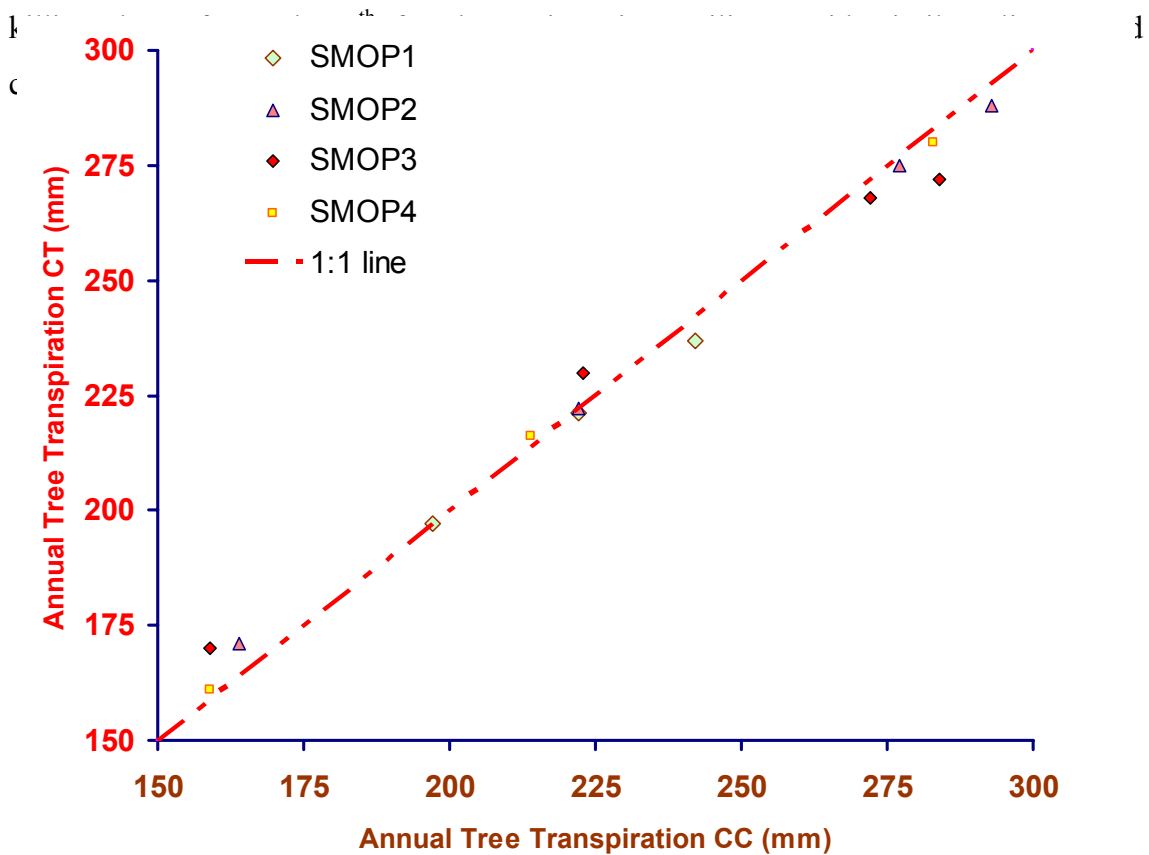


Figure 49: Comparison of olive tree transpiration in cover crop and conventional till for killing date March 15th.

7.5. Summary

Given the conditions of irregular rainfall within the study area, both among the different years and the distribution of the precipitations through the year, the model offers a great disparity in the best killing dates proposed that go from principles of February to late March. The very early killing dates don't guarantee a correct development of the cover to guarantee the protection of the soil. A solution would be to fix a killing date that has been considered as good (March the 15th st) for the three areas that allows to reach an appropriate development of the cover and so decreasing the risk of yield losses in the crop. The model shows how when the proposed killing date is applied or when the killing date is fixed, the differences in the transpiration of the tree, between the utilization of cover crops and the traditional tillage are reduced, and consequently the risk of reduction of the yield is minimum. It is also observed how the establishment of the cover supposes an important reduction of the runoff because being favoured the infiltration is favoured by that and the evaporation from the bare soil decreases.

8. CONCLUSIONS

A simplified water balance specifically designed to evaluate, with a minimum of inputs data, the hydrological fluxes and optimum killing dates for cover crops in rain fed olive orchards has been developed, evaluated and used in the present communication.

The scenario analysis performed for four olive growing areas located in three Mediterranean countries provided some general conclusions about the hydrology of the system, the impact of the cover crops on the orchards hydrological balance, and optimum killing dates of the cover crop.

The optimum killing dates, defined as the killing date that will insure that olive transpiration will not be lower than in the same orchard managed with conventional tillage, range between late January and early April among the different study areas and SMOPS, with the differences due to variability in rainfall, and differences in orchard and soil characteristics. In some situations there is a slight improvement of olive transpiration when used with a cover crop and optimum killing dates. Killing dates before late winter will reduce significantly the benefits of the cover crop in terms of soil conservation. The analysis using OLIVCROP of the impact on tree transpiration of the

use of a killing date of March 15th in all the study areas suggest this date would provide in long term an adequate compromise between soil conservation and olive production, since the simulated impact on tree transpiration is small and limited to dry years usually.

Cover crop soil management has insured moderate or very low runoff losses among the different study areas and SMOPS. Only in very rainy years runoff coefficients predicted for the simulated SMOPS have been moderate or high. Overall cover crop management provide a reduction in runoff generation that it is less than half the runoff predicted for the same orchard managed with conventional till. These decrease in runoff increases soil water availability compared to the conventionally tilled orchard, although this increase it is no proportional to the decrease in runoff given the larger losses by drainage below the rooting depth in the cover crop system.

This increase in infiltration combined with a reduction in soil evaporation from bare soil explains the lack of differences in olive transpiration between the cover crop and the tillage systems. The water surplus it is used as transpiration by the cover crop . Cover crops transpiration until the killing date varies significantly depending on several factors, ranging from 30 to 100 mm. i

The proposed model has demonstrated its ability to provide a basic understanding of the water balance of the olive orchard system and the impact of cover crop management, evaluating different strategies and dates for cover crop killing for a broad range of conditions. Given its simplicity of use, and the limited information needed for its use, it can be used as a management or educational tool to expand the use of cover crops. The killing dates for the cover crops predicted by OLIVCROP agree with those tuned from agronomical trials, and runoff and transpiration predictions are within published values for the situations simulated. Nevertheless this does not preclude the need for a more rigorous validation of the model prediction based on soil water content measurements. This validation is intended as the next step in the model development.

9. REFERENCES

Allen, R., Pereira, L.S., Raes, D., Smith, M. 1998. Crop Evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper N° 56. FAO. Rome.

Gil, J., Rodero, I., Odierna, C. 2003. Inventario de los suelos de la provincia de Córdoba. Diputación de Córdoba. Córdoba

Gómez, J.A, Romero, P., Giráldez, J.V. Fereres, E. 2004. Experimental assessment of runoff and soil erosion on a Vertic soil in southern Spain as affected by soil management. *Soil Use and Management* 20: 426-431.

Gómez, 2005. Effects of soil management on soil physical properties and infiltration in olive orchards: implications for yield. In *FAO Land and Water Bulletin* N° 10, pp 65-69. FAO. Rome.

International Association for Urban Climate. Climate database of the International Association for Urban Climate. Available at <http://www.urbaclimate.net>

Metzidakis, I. (Ed.). 2004. Project Communication N° 2: An overview of productive, ecological and socio-economic functions of SMOPS.

Millgroom, J., Soriano, M.A., Garrido, J.M., Gómez, J.A., Fereres, E. 2006. The influence of a shift from conventional to organic olive farming on soil management and erosion risk in Southern Spain. *Renewable Agriculture an Food Systems*. (In press)

Nicks, A.D., Lane, L.J., Gander, G.A. 1995. Weather generator. In Flanagan, D.C., Nearing, M.A: (Editors). USDA-Water Erosion prediction project. Hillslope profile and watershed model documentation. NSERL Report N° 10. USDA-ARS. West Lafayette, IN.

Pastor, M., Castro, J., Vega, V. y Humanes, M., 1999, Sistemas de manejo del suelo. En “ El cultivo del olivo”, D. Barranco, R. Fernández-Escobar and L. Rallo (Eds.). Mundiprensa. Madrid.

Ritchie, J.T. 1972. Model fro predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8: 1204-1208.

Romero, P., Castro, G., Gómez, J.A., Fereres, E. 2006. Curve number values for runoff in olive orchards as affected by soil management. Submitted to Soil Sci. Soc. Am. Journal.

Testi, L., Villalobos, F.J., Orgaz, F., Fereres, E. 2006. Water requirements of olive orchards: I Simulation of daily evapotranspiration for scenario analysis. Irrig. Sci. 24: 69-76.

Vanderlinden, K., Giraldez, J.V., Van Meirvenne, M. 2004. Assessing reference evapotranspiration by the Hargreaves method in Southern Spain. J. Irrig. Drain. Eng. ASCE 130: 184-191.

Williams, J.R. 1991. Runoff and water erosion. In: Hanks, J., and Ritchie, J.T. (Editors).

Modelling plan and soil systems. Agronomy Series #31. American Society of

Agronomy. Madison.

Xiloyannis, C., Celano, G., Amato, M., Palese, A.M. (Ed.). 2004. Project

Communication N° 3: An overview of crop management, land husbandry and soil &

water conservation measures within the project areas.