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

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1. INTRODUCTION

Deliverable 13 addresses the issue of hydrological features of water balances of different types of olive orchards within the research areas, and Deliverable 15 the determination of optimum dates for killing cover crops that will provide 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 through a simple water balance model that will provide an estimation of 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-CSIC (Cordoba, Spain), 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:


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 form 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 (cm$^3$ cm$^{-3}$). For saturation, field capacity, permanent wilting point and residual water content.
   - Initial soil water content (cm$^3$ 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 ET₀ (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.

\[ P = R + D + T + C + E + \Delta S \]  \hspace{1cm} (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,

\[ T_a = K_a * T_p \]  \hspace{1cm} (2)

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

\[
K_a = \begin{cases} 
1 & \theta_i \geq 0.5 * (\theta_{FC} + \theta_{PWP}) \\
(\theta_i - \theta_{PWP}) / ((0.5 * (\theta_{FC} + \theta_{PWP})) - \theta_{PWP}) & \theta_i < 0.5 * (\theta_{FC} + \theta_{PWP})
\end{cases}
\]  \hspace{1cm} (3)
where $\theta_i$ is the volumetric soil water content of the soil layer, and $\theta_{FC}$ and $\theta_{PWP}$ are the volumetric soil water content corresponding to field capacity and permanent wilting point respectively.

$$T_p = K_p \ast ET_0$$

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.

$$K_p = Q_d \ast F_1 \ast F_2$$

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

$$Q_d = 1 - e^{-K_r V_u}$$

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

$$K_r = 0.52 + 0.79 \ast 10^{-3} \ast D_p - 0.76e^{-1.25 \ast L_d}$$

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.

$$L_d = 2 - \frac{V_c - 20}{100}$$

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.

<table>
<thead>
<tr>
<th>Month</th>
<th>( F_2 )</th>
<th>Month</th>
<th>( F_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.70</td>
<td>July</td>
<td>1.25</td>
</tr>
<tr>
<td>February</td>
<td>0.75</td>
<td>August</td>
<td>1.20</td>
</tr>
<tr>
<td>March</td>
<td>0.80</td>
<td>September</td>
<td>1.10</td>
</tr>
<tr>
<td>April</td>
<td>0.90</td>
<td>October</td>
<td>1.20</td>
</tr>
<tr>
<td>May</td>
<td>1.05</td>
<td>November</td>
<td>1.10</td>
</tr>
<tr>
<td>Jun</td>
<td>1.25</td>
<td>December</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**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.

\[
E_s = ET_0 \times (0.25 + (1 - Q_s) \times 0.75) \quad (9)
\]
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.

$$E_s = \alpha \left( \sqrt{t} - \sqrt{t-1} \right)$$

(10)

where $E_s$ (mm) is daily soil evaporation, and $\alpha$ 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.

$$C = K_{cc} * ET_0$$

(11)

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

$$K_{cc} = K_{fao} * K_a * K_{rad} * K_t$$

(12)

where $K_{fao}$ is 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.

\[
Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad P > 0.2S
\]
\[
Q = 0 \quad P \leq 0.2S
\]  

(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.

\[
S = 254 \left( \frac{100}{CN} - 1 \right)
\]  

(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.
<table>
<thead>
<tr>
<th>SOIL MANAGEMENT</th>
<th>Soil hydrological class</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tree cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tree cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No till with bare</td>
<td>&lt;15%</td>
<td>77</td>
<td>74</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>soil</td>
<td>&gt;15%</td>
<td></td>
<td></td>
<td>90</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>&lt;15%</td>
<td></td>
<td></td>
<td>72</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>&gt;15%</td>
<td></td>
<td></td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td>Freshly tilled</td>
<td>&lt;15%</td>
<td>61</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;15%</td>
<td></td>
<td>72</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Degraded tilled</td>
<td>&lt;15%</td>
<td>71</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well established</td>
<td>&gt;15%</td>
<td></td>
<td>81</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>cover crop</td>
<td>CN₂ = 77 e^{(-0.0208C + 0.000106C²)}</td>
<td>CN₂ = 85 e^{(-0.0072C)}</td>
<td>CN₂ = 90 e^{(-0.0055C)}</td>
<td>CN₂ = 94 e^{(-0.0037C)}</td>
<td></td>
</tr>
<tr>
<td>Poorly established</td>
<td>&lt;15%</td>
<td>72</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;15%</td>
<td></td>
<td>83</td>
<td></td>
<td>92</td>
</tr>
</tbody>
</table>

C is percentage of ground cover by cover crop. CN_{III} = MIN(100.3.3 + 1.05 CN_{II}). CN₁ = 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. CNI and CNIII 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 31\textsuperscript{st}, and cover crop killing date for soil management systems.**
  - Soil volumetric water content $\theta_i$ (cm$^3$ 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 1\textsuperscript{st} to August 31\textsuperscript{st}**
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, Xiloianiannis 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).

![Legend](image)

Location
Year average precipitation
Year average ETa (Hargreaves)

**Figure 3:** Average climate characteristics for the locations involved in the model analysis
<table>
<thead>
<tr>
<th></th>
<th>Plant density, tree/ha</th>
<th>Canopy diameter, m</th>
<th>Slope steepness, %</th>
<th>Soil texture</th>
<th>Soil depth, m</th>
<th>Top soil OM %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ISPOT-NAGREF</strong>&lt;br&gt;(Crete, Greece)</td>
<td>Irrigated: 200-300</td>
<td>Irrigated: &lt;5</td>
<td>Moderate</td>
<td>Sandy-loam</td>
<td>1</td>
<td></td>
<td>3.4-2.1</td>
</tr>
<tr>
<td></td>
<td>Rain fed: 50-80</td>
<td>Rain fed: 8-5</td>
<td>Steep</td>
<td>Clay-loam</td>
<td>&gt;1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70-200</td>
<td>&gt;8</td>
<td>Terraces</td>
<td>Sandy-clay-loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CIFA-IFAPA</strong>&lt;br&gt;(Granada, Spain)</td>
<td>Traditional: 107-122</td>
<td>NA</td>
<td>7-&gt;30</td>
<td>Silty-clay-loam</td>
<td>NA</td>
<td></td>
<td>2.4-1.4</td>
</tr>
<tr>
<td></td>
<td>Intensive</td>
<td></td>
<td></td>
<td>Silty-loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated: 175</td>
<td></td>
<td></td>
<td>Silty-clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IAS-CSIC</strong>&lt;br&gt;(Cordoba, Spain)</td>
<td>SMOPS 1-4: 130-136</td>
<td>SMOPS 1-4: 3.0</td>
<td>SMOPS 1-4: 17-60</td>
<td>Sandy-loam</td>
<td>SMOPS 1-4: 1</td>
<td>4-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMOP 5: 128</td>
<td>SMOP 5: 5.1</td>
<td>SMOP 5: 5-25%</td>
<td>Loam</td>
<td>SMOP 5: 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Loam-sandy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silty-sandy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UNIBAS-SSCFA</strong>&lt;br&gt;(Basilicata, Italy)</td>
<td>Extensive: 70-150</td>
<td>NA</td>
<td>&gt;20-&lt;10</td>
<td>Loam</td>
<td>NA</td>
<td>2.5-1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intensive: &gt;200</td>
<td></td>
<td></td>
<td>Clay-Loam</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**Figure 4:** Orchard characteristics used in section 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between trees (m)</td>
<td>10</td>
</tr>
<tr>
<td>Distance between rows (m)</td>
<td>10</td>
</tr>
<tr>
<td>Row spacing (m)</td>
<td>8</td>
</tr>
<tr>
<td>Grass row spacing (m)</td>
<td>2</td>
</tr>
</tbody>
</table>

**Figure 5:** Soil characteristics used in section 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil depth (cm)</td>
<td>15</td>
</tr>
<tr>
<td>Matric potential (kPa)</td>
<td>1000</td>
</tr>
<tr>
<td>Water content 1</td>
<td>0.34</td>
</tr>
<tr>
<td>Water content 2</td>
<td>0.31</td>
</tr>
<tr>
<td>Water content 3</td>
<td>0.46</td>
</tr>
</tbody>
</table>

**Table 3:** Characteristics of orchard and soil used in the simulations.
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](image_url)

**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 transpirate 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 al least a partial degree of soil protection in very dry areas.

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.

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](image_url)

**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.
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.

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.

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

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.,
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.

<table>
<thead>
<tr>
<th>Area</th>
<th>Tree spacing (m)</th>
<th>Canopy diameter (m)</th>
<th>Rooting depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra</td>
<td>9x9</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Subbetica</td>
<td>10x10</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Area</th>
<th>Soil texture</th>
<th>Hydrological class</th>
<th>Slope %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra</td>
<td>Sandy-loam</td>
<td>C</td>
<td>25</td>
</tr>
<tr>
<td>Subbetica</td>
<td>Loam</td>
<td>C</td>
<td>15</td>
</tr>
</tbody>
</table>

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\textsubscript{Penman_monteith} 1237 mm) for Sierra and Albendin (average annual rainfall 479 mm and average annual ETO\textsubscript{Penman_monteith} 1376 mm). Only average climate data
were available for these locations. To simulate annual variability a 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 $E_{\text{Hargreaves}}$ calculated from the CLIGEN outputs into $E_{\text{Penmann-Monteith}}$ 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.

![Graph showing optimum killing dates for cover crops in Sierra and Subbetica](image)

**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 Subbética 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).

Runoff losses predicted in the same area but with a soil management based on conventional till were much higher, Figure 15. These differences are consistent with differences measured in runoff plots in different studies (Gómez et al., 2003; Castro et
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 16 shows the predicted tree transpiration for both areas and cover crop management for different years, indicating large differences between Sierra and Subbética. These differences, roughly double tree transpiration in Subbética compared to Sierra are proportional to differences in yield that in Subbética are approximately twice the observed in Sierra, Table 4. Figure 16 also indicates how there is an stronger relationship between annual rainfall and predicted tree transpiration in Sierra compared to Subbética. This can be explain by the reduced soil water storage capacity due to reduced rooting depth and soil texture in Sierra.

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

Figure 17 compares the predicted tree transpiration for both management methods, cover crop and conventional tillage, in Sierra and Subbética. The model predicts no losses in transpiration, or a slight increase in Subbética, 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 ETo Penman-Monteith available in most agricultural areas in Andalucia free of charge through the WEB (http://www.juntadeandalucia.es/agriculturaypesca) is an appropriate strategy to minimize the risk of yield losses due to transpiration losses by cover crop competition.
Figure 18 shows differences in water losses through 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 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: 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.

![Diagram](image)

**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.
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.

Results in Figure 21 indicates 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 in 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 indicate that there is space to increase biomass production by cover crop in this area delaying the killing date and using a fix date, what could provide an additional protection and organic matter input to the soil, with a reduced risk of affecting yield.
Other complementary strategy is a reduction in the extension of the cover crop. Although we do not recommended 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 achieve 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 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.

<table>
<thead>
<tr>
<th>SMOP</th>
<th>Average Tree density</th>
<th>Slope (%)</th>
<th>Rainfed (R) or Irrigated (I)</th>
<th>Average production (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>7-15</td>
<td>R</td>
<td>2500</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>7-15</td>
<td>I</td>
<td>4000</td>
</tr>
<tr>
<td>3</td>
<td>110</td>
<td>15-30</td>
<td>R</td>
<td>2000</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>&gt; 30</td>
<td>R</td>
<td>1500</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>7-30</td>
<td>I</td>
<td>4500</td>
</tr>
</tbody>
</table>

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 ET₀ 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.

<table>
<thead>
<tr>
<th>Area</th>
<th>Tree spacing (m)</th>
<th>Canopy diameter (m)</th>
<th>Rooting depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campiña</td>
<td>10 x 10</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Los Montes</td>
<td>9.5 x 9.5</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Sierra</td>
<td>9 x 9</td>
<td>4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 8: Orchard characteristics simulated in the SMOPS analysis

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

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Hydrological class</th>
<th>Slope %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campiña</td>
<td>Clay-loam</td>
<td>B</td>
</tr>
<tr>
<td>Los Montes</td>
<td>Loam</td>
<td>C</td>
</tr>
<tr>
<td>Sierra</td>
<td>Sandy-loam</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 9: Soil characteristics simulated in the SMOPS analysis
In Table 10 the precipitation and ET₀ 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.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Campiña (Jaen)</td>
<td>R</td>
<td>464.6</td>
<td>367.2</td>
<td>428.0</td>
<td>474.0</td>
<td>183.6</td>
</tr>
<tr>
<td></td>
<td>ET₀</td>
<td>1502.0</td>
<td>1466.5</td>
<td>1465.3</td>
<td>1400.0</td>
<td>1565.0</td>
</tr>
<tr>
<td>Los Montes (Granada)</td>
<td>R</td>
<td>795.0</td>
<td>597.8</td>
<td>641.6</td>
<td>707.4</td>
<td>188.0</td>
</tr>
<tr>
<td></td>
<td>ET₀</td>
<td>1398.1</td>
<td>1346.3</td>
<td>1361.6</td>
<td>1287.6</td>
<td>1471.7</td>
</tr>
<tr>
<td>Sierra (Jaen)</td>
<td>R</td>
<td>469.2</td>
<td>458.0</td>
<td>372.0</td>
<td>506.6</td>
<td>173.2</td>
</tr>
<tr>
<td></td>
<td>ET₀</td>
<td>1292.2</td>
<td>1278.5</td>
<td>1292.5</td>
<td>1235.3</td>
<td>1378.0</td>
</tr>
</tbody>
</table>

**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.](image)

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.
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 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.

![Transpiration graph](image)

**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).
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 Xiloyannis et al. (2004). The key SMOPS characteristics are summarized in Table 11.

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

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 of different slope, soil and orchard characteristics.
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$_{0}$Pan$_{evaporation}$ 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.](image)

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.](image)

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 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.

\[ y = 1.73x + 30.2 \]

\[ R^2 = 0.5607 \]

Figure 36: Comparison of annual runoff predicted for cover crop and conventional till in the 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.](image)

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 an 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.

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 Xiloianis et al. (2004). The key SMOPS characteristics are summarized in Table 13.

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

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.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Tree spacing (m)</th>
<th>Canopy diameter (m)</th>
<th>Rooting depth (m)</th>
<th>Slope (%)</th>
<th>Soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOP1</td>
<td>10x10</td>
<td>5</td>
<td>1.2</td>
<td>20</td>
<td>Clay-loam</td>
</tr>
<tr>
<td>SMOP2</td>
<td>6x6</td>
<td>3.7</td>
<td>1.2</td>
<td>20</td>
<td>Clay-loam</td>
</tr>
<tr>
<td>SMOP3</td>
<td>10x10</td>
<td>5</td>
<td>1.6</td>
<td>10</td>
<td>Clay-loam</td>
</tr>
<tr>
<td>SMOP4</td>
<td>6x6</td>
<td>4.5</td>
<td>1.6</td>
<td>5</td>
<td>Clay-loam</td>
</tr>
</tbody>
</table>

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 $ETO_{Hargreaves}$ 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.
Results in Figure 42 indicate how the optimum killing dates vary 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.

\[ y = 2.07x + 14.0 \]

\[ R^2 = 0.606 \]
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.](image)

**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 killing date of March 15th for the regions in Basilicata with similar climate and characteristics to those considered in our analysis seem reasonable.

7.5. Summary

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

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


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


