



OLIVE YIELD AS A FUNCTION OF SOIL MOISTURE DYNAMICS.

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Abstract

Olive (*Olea europaea* L) is one of the most characteristic tree crops from the Mediterranean. The drought tolerance of olive trees makes this species important for economic reasons but also for minimizing erosion and desertification, and for improving the carbon balance of these areas. The production of olive tree crops is dependent on water availability given by the winter rainfall or the irrigation and this is particularly true in the Mediterranean area where the climate is typically characterized by high potential evaporation and low rainfall during the growing season.

The aim of this work is to quantitatively link the olive yield to climate using an ecohydrological approach. A numerical model, describing soil moisture and assimilation dynamics in Mediterranean areas, has been developed. Numerical model describing soil moisture and assimilation dynamics in Mediterranean areas has been developed. Daily evapotranspiration in well watered conditions is calculated with the Penman-Monteith equation while the maximum daily conductance is evaluated with the Jarvis formulation. The Farquhar's model allows to calculate the assimilation in well watered conditions. Using daily stepwise function relating soil moisture condition to actual evapotranspiration and assuming that this relation is also valid for the assimilation, the actual evapotranspiration and the assimilation are evaluated as a function of the same climate and soil moisture conditions. Assimilation is then divided in plant organs, roots, stems, leaves and fruits components using a static partitioning. Integrating daily assimilation over the growing season it is possible to evaluate olive yield.

The results of the numerical model were compared with real yield data collected in a farm located in Sciacca (Sicily, Italy).

Evapotranspiration and assimilation in well watered conditions

Potential evapotranspiration for olive trees was obtained using the Penman-Monteith equation [Brutsaert, 1982; Dingsman, 1994; Federer, 1979].

$$E_p = \frac{\lambda \gamma_w g L_{ul} g_{m,p} \rho D + g L_{ul} S \phi}{\rho_w \lambda \gamma_w (g L_{ul} + g_{m,p}) + g L_{ul} S} \quad \text{where}$$

- λ : Latent heat of water vaporization
- γ_w : Psychrometric constant
- L_{ul} : Leaf area index (here equal to 1.4)
- S : Slope of the curve relating saturation vapour pressure to temperature
- ϕ : Leaf available energy, here assumed to be equal to the daily effective irradiance on the leaves.
- $g_{m,p}$: Series of leaf boundary layer and atmospheric conductance
- g_s : Stomatal conductance, calculated through the Jarvis' empirical formulation [Jarvis, 1976], as a function of solar radiation ϕ , ambient temperature T , leaf water potential ψ_l and potential saturation deficit D .

Potential assimilation. The net CO₂ flux per unit leaf area is $A_n = g_{ab,CO_2} (c_a - c_l)$ where c_a and c_l are the CO₂ concentration in the atmosphere and leaf pores and g_{ab,CO_2} is given by the series of the CO₂ stomatal, leaf boundary layer and atmospheric conductance. It is usually assumed that $g_s = 1.6 g_{ab,CO_2}$, $g_{b,CO_2} = g_s / 1.37$, $g_{a,CO_2} = g_s$. For the sake of simplicity the daytime respiration will be neglected, thus the dependence of A_n on f_c , T_l is given by the model of [Farquhar, et al., 1980] $A_n \equiv A_{p,s,T_l} = f(A_n, A_p, A_s)$ Where A_n is the assimilation rate limited by rubisco activity, A_p is the assimilation rate when the photosynthetic electron transport limits RuBP regeneration, and A_s is the assimilation rate when photosynthesis is limited by T_l . All model parameters are the same as in [Diaz-Espejo, et al., 2006]

Figure 1: Stomatal conductance, potential evapotranspiration and assimilation as a function of climate forcing.

Soil moisture dynamics

Soil moisture dynamics were taken into account by means of a simple numerical ecohydrological model [Pumo, et al., 2008; Viola, et al., 2008], which presents a good adaptability to Mediterranean areas. This model considers a water balance vertically averaged over the root zone, under the simplifying assumption that the lateral water contributions, mainly due to topographic effects, can be neglected. According to this model, soil moisture dynamics can be evaluated solving the soil water balance, through a finite differences method:

$$\Delta s = s_{i+1} - s_i = \left(\frac{\phi_i}{n - Z_i} - \frac{Z_i}{n - Z_i} \right) \cdot \Delta t$$

where Δt is the temporal step (daily), while ϕ_i and Z_i are the infiltration and the losses, both referred to the time t_i . No interaction between the active soil layer and the water table is considered. Moreover it is assumed that the effects on the soil surface driven by raindrop impact (i.e. soil crusting, sealing, etc.) are neglected. The porosity n depends only on soil texture, while the rooting-deep Z_r is assumed to be 100 cm, which is common for olive trees, and both are time invariant. The model works at a spatial scale of few meters, considering homogenous soil and vegetation. The model is forced by historical rain input, thus the infiltration (ϕ_i) is given by the precipitation (Figure 3a) minus the water lost through canopy interception (fixed threshold) and the runoff (Dunnian saturation mechanism). The water losses from the soil (Z_i) are given by the sum of evapotranspiration and leakage losses according to the stepwise function shown in Figure 2 [Laio, et al., 2001].

Soil moisture controls the actual daily rate of evapotranspiration, but also the daily net assimilation [Daly, et al., 2004b; Larcher, 1995] as illustrated in the figure 2. Figure 3 shows the rain input, the soil moisture dynamics and the traces of potential (blue) and real (red) evapotranspiration and assimilation for the case study.



Given the daily total assimilation the process that lead to olive yield is quite simple. First the assimilation is integrated over the growth period of the olive fruit, which lasts for 5 months [Connor, 2005]. Here the seasonal pattern of fruit growth is neglected, thus no interruption is considered during the summer water shortage. The next step is the biomass partitioning. Here a static partitioning is supposed to bring 65% of the total biomass above ground; the latter should be divided in stems, leaves and fruit (40%) [Connor, 2005]. A comparison between measured and modelled olive yield is reported in Figure 4. The model seems to reproduce quite well the yields in the "on" years 2004 and 2006, while lacks in the "off" years.

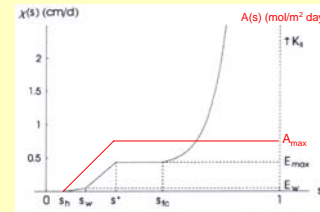


Figure 2: Stepwise function relating soil moisture to evapotranspiration and leakage (black line) and to assimilation (red line).

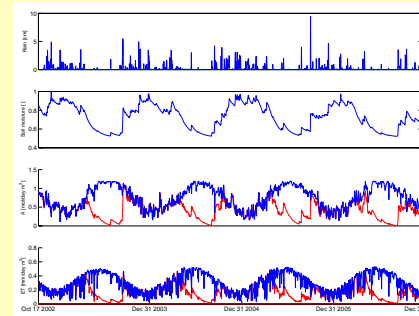


Figure 3: Rainfall input (a), Soil moisture trace (b), Potential (blue) and real (red) evapotranspiration (d), and real (red) assimilation (c).

Olive yield

The attempt to relate water use to the plants yields is an old topic in agronomy [Hanks, 1974]. In this pioneering work a basic assumption was that the ratio of actual to potential dry matter yield is directly related to the ratio of actual to potential evapotranspiration. Notwithstanding the evaporative fluxes were estimated in an over-simplified way, a good fit of predicted versus measured yield was found (sorghum, corn, grain). In this work a more complex approach is considered. The interrelation between soil moisture dynamics and evapotranspiration is explicitly considered and the assimilation rate is modelled as a function of soil moisture [Daly, et al., 2004b; Larcher, 1995].

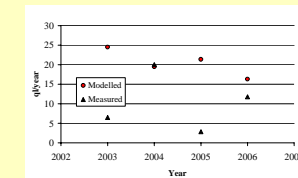


Figure 4: Comparison between modeled and measured olive yield

Data

The case study area is Sciacca, a little town located in the southern Italy. Daily average incoming shortwave radiation, daily mean air temperature, relative humidity, wind speed at the Sciacca station were registered from SIAS (Servizio Informativo Agrometeorologico Siciliano, <http://www.sias.regione.sicilia.it/>). Climatic data are available from 17/10/2002 to 31/12/2006. Those data, shown in Figure 1, were used to calculate daily potential evapotranspiration and assimilation.

Olive yield data, which are necessary for the model validation, were provided from a private farmer. The orchard taken into consideration in this study has an extension of 6,80 ha. Trees were planted before the 1900, spaced 7 by 7 m. The cultivar is "Nocellara del Belice" (DOP). The average vegetation coverage is very low, near 0.25. There is no irrigation system in the farm.



Conclusions

This work is an attempt to relate climate, soil moisture dynamics and olive yield. Without soil moisture limitations the Penman-Monteith equation and the Farquhar's model allow to calculate potential transpiration and assimilation (see Figure 1) as a function of climate forcing. Using a stepwise function, relating soil moisture to evapotranspiration and assimilation (see Figure 2), it is possible to evaluate, through a numerical model, water and CO₂ fluxes explicitly considering soil water deficit (see Figure 3). Integrating the assimilation rates over the olive growth period and considering a static biomass partitioning the olive yield is finally obtained. The comparison between modelled and measured data is encouraging especially in the "on" years (see Figure 4).

Future works

- It is necessary to validate the model over a wide number of case study. It is not a trivial task to collect reliable contemporary climatic and olive yield data, especially because the latter are often "corrupted" by human activities, such as pruning, or by plant diseases or parasites attacks.
- Olive alternate bearings should be explicitly included
- The static biomass partitioning in soil drought conditions is not yet verified for olive trees, while seem to be a good hypothesis for almond trees [Heilmeyer, et al., 2001]. However a dynamic biomass partitioning, i.e. a different fruit allocation for "on" and "off" years, could resolve the discrepancies emerged in this study (see Figure 4).

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