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Article

Preliminary Results on the Evaluation of Factors Influencing Evapotranspiration Processes in Vineyards

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Abstract: The paper summarizes the preliminary results from the analysis of data collected during the 2008 and 2009 vegetative seasons in a northern Italy vineyard (*Vitis vinifera* L., Barbera variety) and the simulations carried out in the same period with the land surface model UTOPIA. The aim of the work is to study the influence of the meteorological factors on the plant conditions. We collected a set of standard and advanced meteorological, physiological and physical data and we investigated the performance of UTOPIA in describing the different components of the energy and hydrological processes (in particular the evapotranspiration), with a special focus on the vegetation and soil. The comparison between observed data and UTOPIA simulations showed satisfactory results for the soil variables (RRMSE ranging between 15% and 40%, and correlation coefficients of 0.9). Net radiation and sensible heat fluxes RRMSE (30% and 63% respectively) suggest that both the calibration of the vegetation parameters (including the influence of the grass among vine rows) and the availability of more specific measurements are very important.

Keywords: vineyard; sonic anemometer; evapotranspiration; sensible heat fluxes; LSPM; UTOPIA; Barbera vine

1. Introduction

Wine is one of the most important product in the Italian economy, and especially in Piedmont region (northwestern Italy), where the area covered by vineyards is 52,200 ± 700 ha and the wine production is 2.8 ± 0.4 10^3 hL (these numbers represent the average in the last 10 years, adapted from Baccaglio [1]). Many studies were recently carried out in order to deepen the understanding of grapevine (*Vitis vinifera* L.) agro-ecosystem and improve the characteristics and quality of its final product, the wine.

In this regard, this work is inserted in an applicative research project aimed to study the effects of chemical and biophysical factors on the grapevines. The expected results, favored by the multidisciplinary collaboration of different experts and wine companies, will hopefully allow to elaborate tools able to provide the viticulture operators with information useful to support and improve crop management and wine-making.

The grapevine water consumption (*i.e.*, the actual evapotranspiration ET) is among the most important factors that could be related to the wine quality. In its evaluation, the major issues are the nonlinear interactions among soil, plants and atmosphere. With the purpose to optimize water irrigation in grape vineyards, Ortega-Farias *et al.* [2] and Rana *et al.* [3] proposed different methods for estimating ET from meteorological measurements, and validating them by quantifying the energy respectively absorbed by vines and soil surface (*i.e.*, the net radiation, NR, and the soil heat flux, G, used in the Bowen ratio method). The sensible heat flux (SHF) can be considered as the major contributor to the surface energy balance, also due to the widely spaced geometry of most vineyards (Spano *et al.* [4]), in which a large portion of bare soil is comprised among the vine rows. This geometry and the plant conditions can be described by the fraction of surface covered by vegetation (σ_v) and the leaf area index (LAI), which represent parameterization keys factors in land surface models for the ET evaluation.

The aim of the work is indeed to study the links between the meteorological quantities and the status of the grapevines, with a special focus on the ET processes.

Since direct measurements of ET are not available, we investigate the application of the biophysical land surface model UTOPIA (University of TOrino land surface Process Interaction model in Atmosphere). UTOPIA is a diagnostic model that require a continuous dataset of meteorological initial and boundary conditions and a set of soil and vegetation parameters, mainly fixed in time. The ones used in the ET representation in UTOPIA for the vineyards were calibrated the first time in a neighbor Nebbiolo vineyard by Prino *et al.* [5]. In the present study, UTOPIA is applied to evaluate the energy and hydrological balance components for non-irrigated vertical shoot-positioned (VSP) Barbera vineyard. The model was processed in two different ways. In a early stage it was kept as in the Prino *et al.* paper [5], then a different vegetation parameterization (*i.e.*, vegetation data assimilation), based on the observations, was tested for 2008 and 2009 years, in order to check the model response. The first validation was possible thanks to an extensive field activity, enriched in 2009 with measurements of micrometeorological (fast response wind velocity and SHF) and hydrological (subsurface temperature and humidity) data. In that light, the work was performed for the first time in northern Italy vineyards.

2. Materials and Methods

2.1. The Land Surface Model Theory

UTOPIA (University of TOrino land surface Process Interaction model in Atmosphere) is the upgraded version of the LSPM (Land Surface Process Model), a biophysical diagnostic model developed at the Department of General Physics "A. Avogadro" of the Torino University by Cassardo *et al.* [6]. The first study on the UTOPIA parameterization for water air-vegetation exchanges (including the transpiration processes) as a function of the meteorological data was carried out for a specific vineyard site located in Piedmont in the work of Prino *et al.* [5].

The water and energy exchange processes, mainly taking place along the vertical direction, are described in UTOPIA as vertical fluxes (transfer of a quantity per unit of surface and time) between vegetation or bare soil and the top of the surface layer. The model estimates them using the resistance-analogy theory, in which the flux, assimilated to a generalized current, is represented by the ratio between a temperature or humidity difference (generalized potential difference), multiplied by opportune dimensional parameters, and the resistance. The latter is related to the wind velocity and its value is strongly linked to the atmosphere stability [7].

In the presence of vegetation, the turbulent radiative, energy and water vapor fluxes are evaluated by splitting each value into two components (one for the vegetation and one for the bare soil), and the cumulative value is evaluated above the vegetation. To model the water processes and the propagation of the thermal wave in the underground terrain, the soil is subdivided in several layers. On the contrary, the vegetation is considered simplified and parameterized as a single layer ("big-leaf" approximation), and its complexity is represented by some physiological variables, as the Leaf Area Index (LAI), the vegetation height, the mean leaf dimension, the albedo and the fraction of the vegetation over the ground. These quantities are usually taken from an extension of the global Wilson and Henderson-Sellers database [8], reported in Cassardo [9], in which some of them are fixed while the others vary during the year according to the root zone temperature, or can be derived from other database (such as ECOCLIMAP [11]).

The physical processes described in UTOPIA include the atmosphere-surface momentum exchange, the energy (net radiation, sensible, latent and conductive heat fluxes) and the hydrological (rainfall, evapotranspiration, runoff and drainage) budgets. The energy available for water vapor phase transitions (evaporation or condensation) in the air, the soil, and at the canopy-air interface is the latent heat flux. The sensible heat flux is the turbulent flux that warm or cool the surface layer, including the canopy, the air in contact with the biosphere and the soil. It depends on the difference between the air and the surface temperatures. The conductive heat flux, propagating (upward or downward) energy among the soil surface and the ground, is evaluated as the residual of the energy balance. Despite the UTOPIA model considers also the presence of snow and the physical processes correlated with the soil freezing, as in this work only the vineyard vegetative season is studied, these parameterizations will not be mentioned here.

In the present application, the sensible heat flux plays an important role in the energy balance, due to the vineyard geometry: Widely spaced plants allow the penetration of solar radiation and air turbulence into the canopy. This effect is described by the model partitioning of the total heat flux (SHF) into its bare soil (SHF_g) and canopy (SHF_c) components, *i.e.*, $SHF = SHF_g + SHF_c$:

$$SHF_c = \rho_{air}\, c_p\, s_b\, (\vartheta_c - \vartheta_{ac})\, \sigma_v \tag{1}$$

$$SHF_g = \rho_{air}\, c_p\, s_d\, (\vartheta_s - \vartheta_{ac})\, (1 - \sigma_v) \tag{2}$$

where SHF, SHF_c and SHF_g are expressed in Wm^{-2}, ρ_{air} is the dry air density (1.22 kg m^{-3}), c_p is the specific heat capacity of dry air (1,003 J kg^{-1} K^{-1}), ϑ_c is the canopy potential temperature (K), ϑ_{ac} is the air-canopy potential temperature (K), ϑ_s is the soil surface potential temperature (K) and σ_v is the fraction of ground cover by vegetation (hereafter vegetation cover). According to Bonan [10], s_b and s_d are the laminar leaf and the aerodynamic (beneath canopy) conductances, expressed in the units ms^{-1}. The former refers to a few millimeter air layer surrounding the leaves, while the latter considers the layer of atmosphere included between the air-canopy interface and the soil surface (the so called roughness length for heat exchange). In the case of the vineyard, this last layer can roughly be considered as coincident with the lower half of the grape canopy, thus ϑ_{ac} become the air temperature measured into the canopy at an height equal to half the canopy height.

The evapotranspiration (ET), expressed in water vapor flux units, enters also in the hydrological balance.

In general, the ET is a term used to summarize all air, soil and plants physical mechanisms transforming liquid water into water vapor, or vice versa. The presence of vegetation modulates the evaporation from the soil and contribute further to the vertical water vapor flux exchange in the atmosphere, through the transpiration. This process differs from the evaporation since it occurs in leaf guard cell cavities (stomata), which physiologically control it by modifying their aperture. Moreover, transpiration can occur also when surface soil is dry, since the water can be extracted by the vegetation in the whole root layer. Through the vascular system of the roots, stems and branches, the water is pulled up to the leaf stomata, where transpiration take place. The air in the stomata is then saturated, and water can exit into the environment, due to a vapor-pressure gradient.

UTOPIA describes the transpiration flux (TRF) as a sum of the contributions related to the wet (f_w) and dry ($1 - f_w$) leaf fractions:

$$TRF = -\rho_{air}\lambda\, [q_{ac} - q_*(T_c)] \left[f_w(\frac{LAI}{r_b}) + (1 - f_w)(\frac{LAI}{r_b + r_s}) \right] \tag{3}$$

where λ is the latent heat of evaporation and/or fusion, q_{ac} is the specific humidity (g kg^{-1}) beneath the canopy, q_* is the saturated specific humidity in the leaf cavities, dependent on the leaf temperature T_c (°C), LAI is the Leaf Area Index, r_b is the resistance corresponding to s_b (Equation 1) and r_s the stomatic resistance dependent on hydrological and meteorological factors [5].

2.2. *Sonic Anemometer and Flux Measurements*

The statistical approach to atmospheric turbulence, the eddy-covariance method, evaluates the fluxes of momentum, heat and moisture as the covariance of the vertical wind velocity component with the scalar quantity object of the exchange (wind horizontal component, temperature and specific humidity, respectively) considering their departures from their relative mean values. Hence, sonic anemometers can be considered instruments suitable for direct measurements of momentum and heat fluxes, due to their high-frequency acquisition rate (around 20 Hz). Latent heat fluxes can also be measured, coupling the anemometer with other fast response instruments ([2,12]). Besides measuring the three components of the air wind vector, the sonic anemometer evaluates the sound speed c, which depends on the thermodynamic properties of the propagation fluid, according to the expression:

$$c^2 = \gamma_d \, R_d \, T_s \tag{4}$$

where γ_d is the ratio between the dry air specific heat capacity of at constant pressure ($c_{p_\mathtt{d}}$) and volume ($c_{v\mathtt{d}}$) and $R_d = c_{p_\mathtt{d}} - c_{v\mathtt{d}}$ is the dry air gas constant (287 J kg^{-1} K^{-1}). T_s is the so-called sonic temperature, in moist air given by:

$$T_s = T\,(1 + \eta q)\,. \tag{5}$$

where q is the specific humidity and η is usually assumed constant and equal to 0.51. This precision is sufficient for the majority of meteorological applications, while a more accurate value is proposed by [13]. The above expressions allow to split, at first approximation, the heat flux in:

$$\overline{w'T'} \cong \overline{w'T'_s} - \eta\,\overline{T}\,\overline{w'q'} \tag{6}$$

where the apices always indicate the departures from the average value over a period useful to separate the turbulence from the mean flow (usually chosen equal to 30 minutes). Two example of the difference between the "sonic" sensible heat flux ($\overline{w'T'_s}$) and the actual sensible heat flux ($\overline{w'T'}$) related to field experiments can be found in [14] and [12]. The first work shows a general validity of the approximation (Equation 6) with a prevail of the first term on the right-hand side. In some circumstances however the difference may be relevant and the direct sonic measurement can only give an idea of the order of magnitude of $\overline{w'T'}$ [12].

To evaluate the fluxes, an additional issue must be taken into account because the presence of a slope surface may distort the vertical flux propagation. Since Piedmontese vineyards are located on the eastern, western and southern slopes of Monferrato, Langhe and Roero hills, where the inclination of the surfaces is often not negligible, the effects of the surface tilt can produce relevant distortions. For this reason, the Planar Fit Method [15] was used in order to evaluate the heat flux in this complex geometry.

2.3. *Experimental Activity*

2.3.1. Site characterization

The field experiments were carried out during the 2008 and 2009 vegetative seasons at Cocconato, a Piedmontese site selected as representative for the Barbera variety (45°05'N; 08°03'E; 311 m a.m.s.l.).

The soil texture of the uppermost 30 cm was analyzed and classified as silty clay loam. The Barbera vines were placed in rows 2.5 m apart from each other, aligned with the N-S direction and trained on a vertical shoot-positioned (VSP) system. Vines width was of about 0.5 m, while root depth was evaluated in about 0.4 m (this value was measured in one case at a distance of 0.5 m from the plant bases). As in most commercial vineyards, soil surface below the vines is bare, while between the rows there is short grass, which height, cover and LAI vary with an annual cycle also depending on the vinedresser managements.

From a climatic point of view, in the last 10 years (assumed as a reference period and hereafter denoted as "normal"), the area marked off within a 30 km radius around Asti (44°55'N; 08°11'E; 175 m a.m.s.l.) was characterized by average daily summer temperature of 22.3 ± 0.7 °C. During both 2008 and 2009 vegetative seasons, the average temperatures were slightly higher, while strong positive anomalies (about 3 °C) were recorded during May and August 2009. Normal average annual rainfall was 660 ± 66 mm, falling mainly during the spring and late summer months (*i.e.*, fall months). On the contrary, early spring 2008 was drier than normal and late spring and summer months were on average 30% wetter than the climatic values. During 2009, spring rainfall was harder (about 150 mm) than normal while the other season rainfall amounts were closer to normal values. In conclusion, during the 13-month period from April 2008 to April 2009 about 1,230 mm were accumulated, a value much larger than the normal one (714 ± 76 mm) and statistically unusual.

2.3.2. Weather and energy balance measurements

In the analyzed vineyard, the instruments were positioned for continuously monitoring the meteorological data (with 10 minutes frequency acquisition). Air temperature and relative humidity were measured both above (in a shelter) and within the canopy (using H08-032-IS, Hobo Pro RH and Temperature Data Logger). The Photosynthetically Active Radiation (PAR), *i.e.*, the solar radiation within the spectral range of 400–700 nm, was continuously recorded above and within the canopy (S-LIA-M003, Photosynthetic Light Smart Sensor, Hobo). The solar global radiation (GR), was estimated indirectly from above canopy PAR data on the basis of spectral considerations, by assuming the ratio between PAR and GR as constant and equal to 0.4 (value found by Prino [16] in a neighbor Nebbiolo vineyard).

At the beginning of the 2009 vegetative season, some additional instruments were installed into the top layer of the soil, in order to monitor the volumetric water content (S-SMA-M005 Dielectric Aquameter EC-20, Decagon) and the temperature (S-TMA-M006 8-Bit Temp Smart Sensor, onset). The initial position of the installation was, for both sensors, 15 cm below surface, but the soil compaction during the 2009 spring caused a variation of the sensor depth, which was re-evaluated at 10 cm during mid July. In addition, a fast response data 3-D sonic anemometers (model Solent R2, by Gill Instruments) was installed in the period May–October 2009. Its position was 3 m above the soil surface (*i.e.*, about 1 m above the maximum canopy height). Finally, since July 2009, also a net solar radiation transducer (t056 TRADNT, SIAP+MICROS) was positioned on a meadow, close to the vine rows head.

2.3.3. Plant measurements

The wine producers reserved for these experiments four plants, in order to represent the average vine conditions. A fortnightly special and manual collection of physiological data from these plants was performed from the shooting till the harvest time in order to monitor plant ET and growth. The data useful for this study are: canopy height and width, leaf diameter and LAI. In particular the LAI (the area of total leaves per unit of ground area), was the parameter used in UTOPIA in order to consider the exchange processes relative to the entire plant starting from the calculations performed for one leaf (procedure commonly adopted by many LSMs).

There are different methods — direct and indirect — for measuring LAI [17]. In this work, an indirect method was chosen, which uses the measurements of the radiation over the top of the vegetation (I_0) and of the PAR intercepted by the canopy (I_t) with a solarimeter bar (Multi-PAR Probe, Tecno.El) placed within the canopy and perpendicularly to the rows, in order to regard the horizontal section of the plants. These data can be combined using the Lambert-Beer adapted formulation to give the LAI according to the relationship:

$$LAI = \frac{\log(I_t/I_0)}{k}$$

where k is the extinction coefficient, imposed constant and equal to 0.5 for grapevine.

The measures of the mean horizontal section of the plants were useful to quantify the grapevine vegetation cover (σ_v), evaluated as the ratio between the surface in which the radiation is intercepted (A_p) and the ground surface unit (A_g), according with the relation:

$$\sigma_v = \frac{A_p}{A_g}$$

2.4. *Model Setting and Accuracy*

Some simulations relative to the period May 2008–September 2009 were performed for the Barbera grapevine in Cocconato using UTOPIA. Among the initial and boundary conditions needed by the model (with a temporal rate not lower than a datum per hour), the following meteorological data were preprocessed: solar global radiation, air average temperature and humidity (measured in a Stevenson screen above the vegetation), pressure, precipitation and wind velocity. Atmospheric pressure was not measured at the site, but at Pino Torinese, a station about 50 km far, and adequately scaled taking into account the different height of the Cocconato station. To avoid the problem of the missing data, due to some temporary blackouts or failures in the acquisition systems, the data gaps were filled with weighted averages of the meteorological data collected in some neighboring stations belonging to the agrometeorological networks of ARPA Piemonte and RAM (in Cocconato, Montechiaro d'Asti, Crea, Buttigliera d'Asti and Casale Monferrato sites).

According to the composition of sand, silt and clay, the soil texture was categorized in the class number 7 (silty clay loam) and the corresponding soil parameters were set according to Clapp and Hornberger [18].

Two different methods were used for initializing the vegetation parameters, in order to evaluate the impact on the simulation of the two procedures.

In the first one, a new class of parameters (called vineyard) was created and added to the Wilson and Henderson-Sellers database [8]. Their values were selected both from literature and from the present experimental activity (this simulation will be hereafter referred as "control run"). As shown from the Table 1 all parameters but vegetation cover and LAI were considered fixed during the year, while the latter two varied between a minimum winter value and a maximum summer value according with mean root zone temperature (Dickinson *et al.* [19]).

In the second simulation, hereafter named "experimental run", LAI, canopy height and vegetation cover, measured during the experiment, were given directly as input to the model. LAI and vegetation cover were chosen as vegetation key factors in UTOPIA as a result of the model sensitivity analysis tests applied to the Piedmont area (Cavalletto *et al.* [20]).

Table 1. List of vegetation parameters used to define the new class vineyard in the adapted Wilson and Henderson-Sellers database.

Vegetation albedo	0.23	[2] and Prino [16]
Vegetation emissivity	0.96	[16]
Minor leaf characteristic dimension [m]	0.11	this work
Vegetation root depht [m]	0.4	this work
Canopy heigh [m]	2	this work
Minimum stomatal resistance [s/m]	120	this work
Vegetation cover	0.2–0.59	adapted from Dickinson *et al.* [19]
Leaf area index	0.2–3.5	adapted from Dickinson *et al.* [19]

Concerning these values, we underline a problem that could affect the simulations. The observations refer just to the vines, and not to the grass present between the rows, about regularly cut off. The physical characteristics of the two kinds of vegetation are clearly quite different, and, due to the relatively large distance between the rows, the grass effect can be important, especially during winter and early spring, when grass is green well before the vines germination. In the simulations, we decided to mostly discard grass influence, as a sort of first-order approximation, and because UTOPIA considers only one kind of vegetation. Despite the possible non linear interactions of vines and grass effects on the surface processes, retaining only the vine parameters was considered better than arbitrarily modifying the observations of LAI, vegetation cover and canopy height. The only effect of the presence of grass was included in the vegetation cover, adding to the measurements performed in the vineyard an additional and constant value of 20% during the whole two-year simulation.

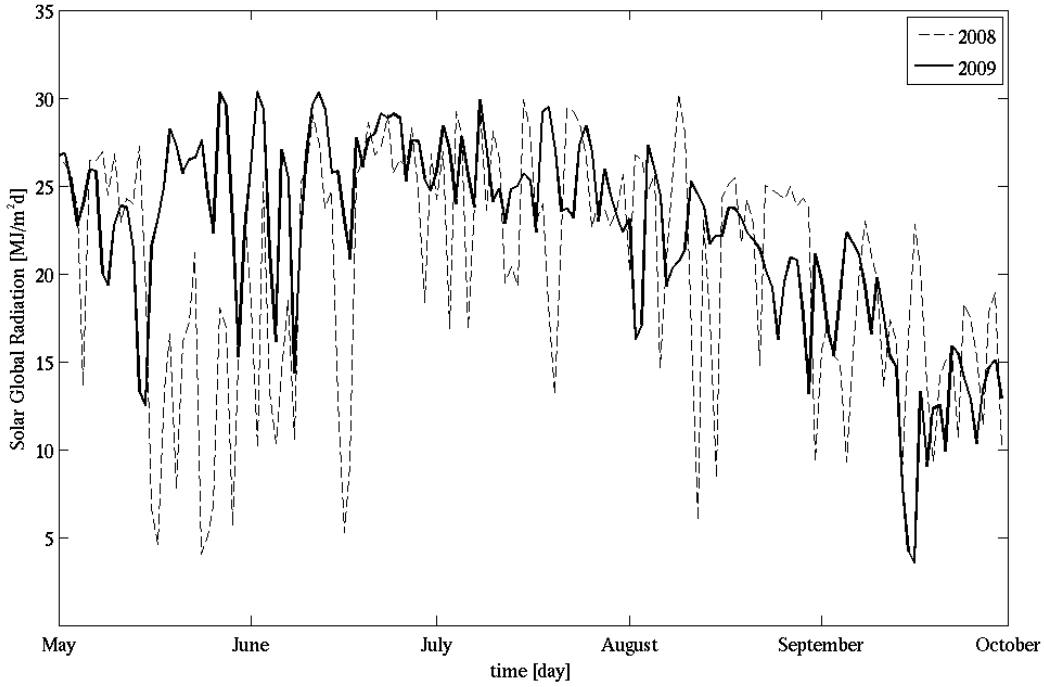
In order to quantify the model accuracy two indices, defined by Mayer and Bulter [21], were used: the relative root mean square error RRMSE (whose range varies from 0%, the optimum, to positive infinity) and the coefficient of determination r^2 (whose range varies from 0, index of complete decorrelation, to 1, corresponding to the maximum correlation).

3. Results and Discussion

3.1. Experimental Results

Cocconato daily values of GR ranged between 4 and 30 MJ m^{-2} d^{-1} in both 2008 and 2009, with their maxima recorded during June, July and early August (during 2009), when the daily variability appeared lower. Comparing 2008 and 2009, an appreciable difference came out in the second half of May: the 2009 values were on average 15 MJ m^{-2} d^{-1} higher than those of 2008 (Figure 1).

Figure 1. Daily values of solar global radiation (in MJ m^{-2} d^{-1}), deduced by PAR observations as mentioned in subsection 2.3 during 2008 and 2009 vegetative seasons relative to the Barbera cultivar at Cocconato.



The mean daily temperature (Figure 2) and humidity (Figure 3) at screen height revealed that the 2009 vegetative season was generally warmer and drier than the 2008 one, in particular during May, August and September. This discrepancy is in part confirmed by the monthly cumulated precipitation recorded (Figure 4), larger for 2008 (958 mm) than for 2009 (772 mm). The rainiest months were December 2008 and April 2008 and 2009, during which several episodes of intense rainfall were observed in the whole Piedmont region.

The 2009 vegetative season was analyzed with greater detail, because the number of instruments placed in the vineyard increased. The horizontal wind velocity (not shown) above the vineyard was generally low, with daily average values lower than 1 ms^{-1}. More precisely, the daily averages of minimum, mean and maximum horizontal wind speeds in the period May–September, 2009, were 0.51, 0.80 and 1.64 ms^{-1}, respectively ($\pm$ 0.02 ms^{-1}). The peak episodes tended to coincide with the passage of cyclonic areas over the site.

Figure 2. Mean daily air temperature (in °C) measured in the shelter during 2008 and 2009 vegetative seasons above the Barbera vines at Cocconato.

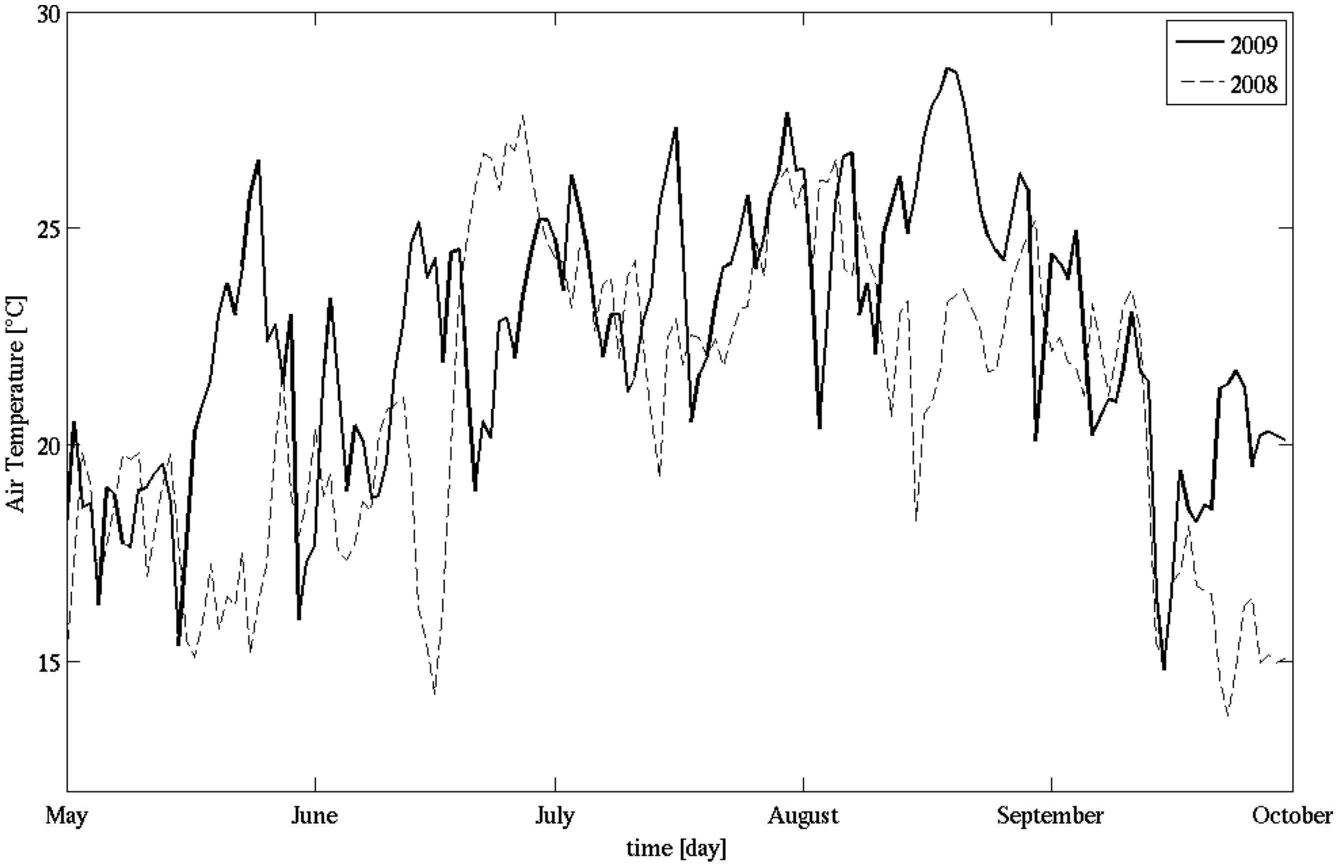


Figure 3. Mean daily air relative humidity (in %) measured in the shelter during 2008 and 2009 vegetative seasons above the Barbera vines at Cocconato.

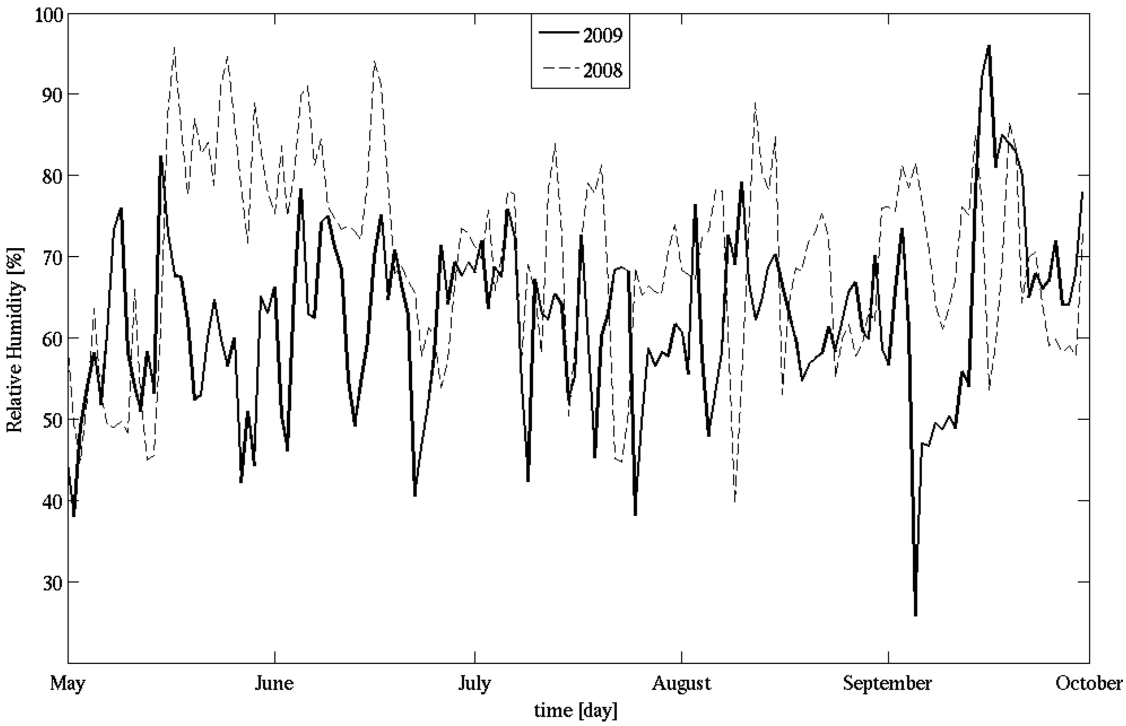


Figure 4. Monthly cumulated precipitation (in mm) measured at Cocconato vineyard in 2008 and 2009.

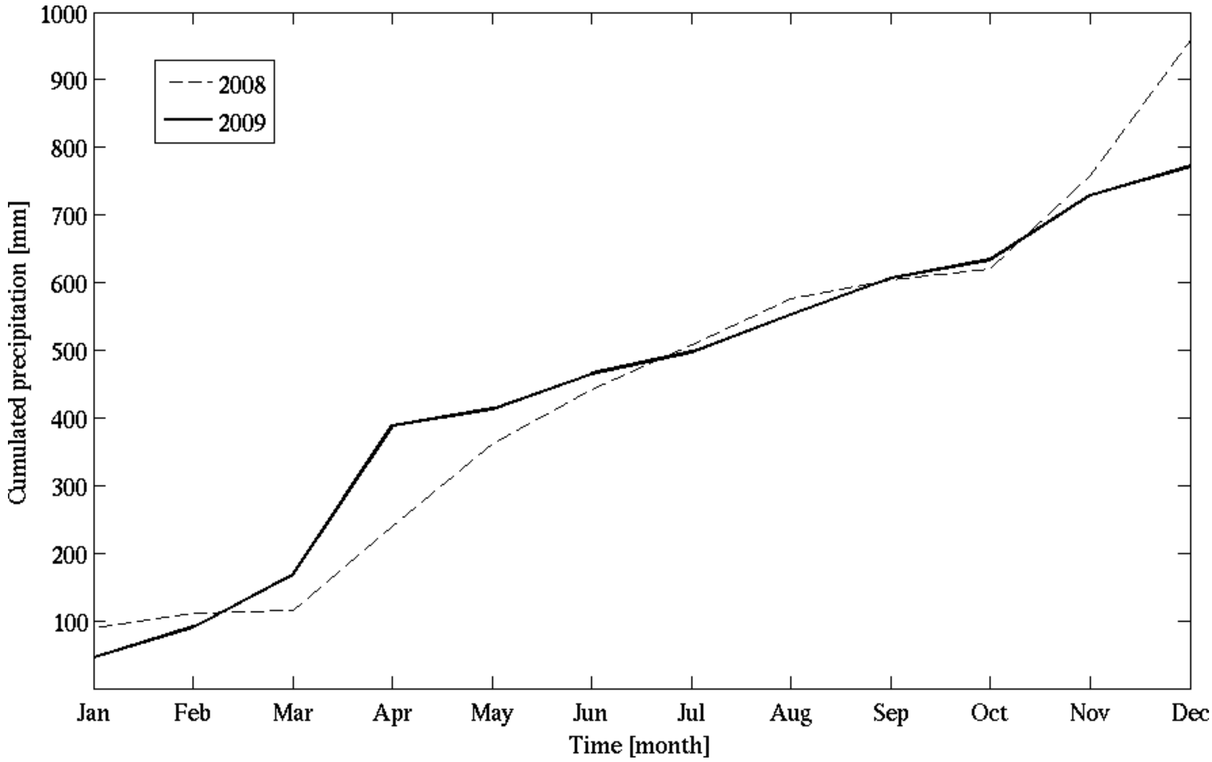


Figure 5. Volumetric soil water content (in m^3 m^{-3}, left scale) measured near Barbera vine rows at Cocconato 10 cm below the soil surface, and daily cumulated precipitation (in mm, right scale) measured at Cocconato during the 2009 vegetative season. For the sake of reference, the wilting point for the silty clay loam soil is 0.22 (m^3 m^{-3}), while the porosity is 0.47 (m^3 m^{-3}) [18].

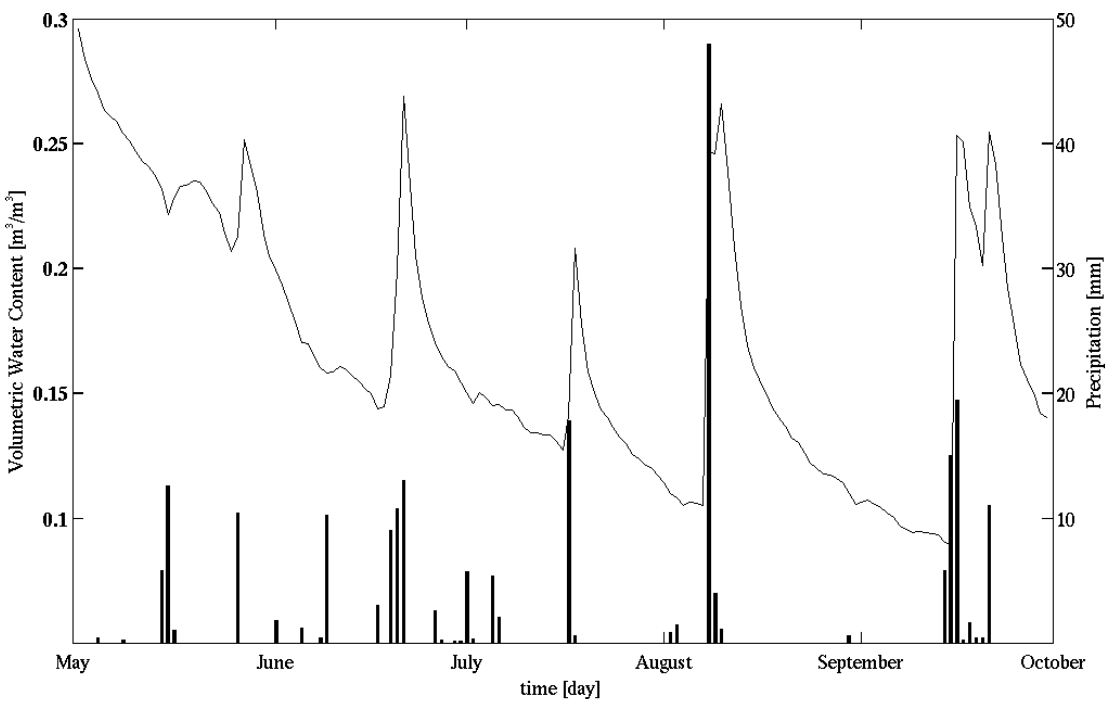


Figure 6. Air temperature measured in the shelter, above the canopy, compared to soil temperature measured at 15 cm below the soil surface near Barbera vine rows at Cocconato, during the 2009 season at Cocconato (both in °C).

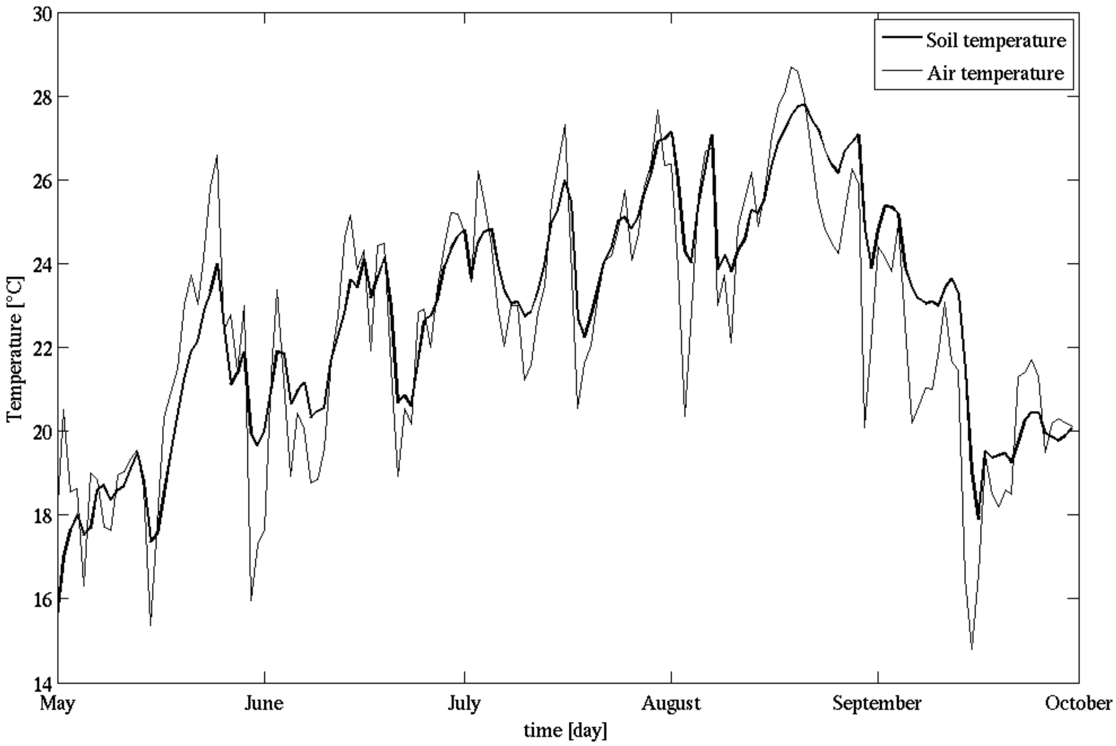


Figure 7. Mean daily net radiation (thin line), measured at the flank of the vineyards, and "sonic" sensible heat flux (thick line), evaluated by sonic anemometer measurements above the vineyards, relative to Cocconato during the 2009 growing season (both in Wm^{-2}).

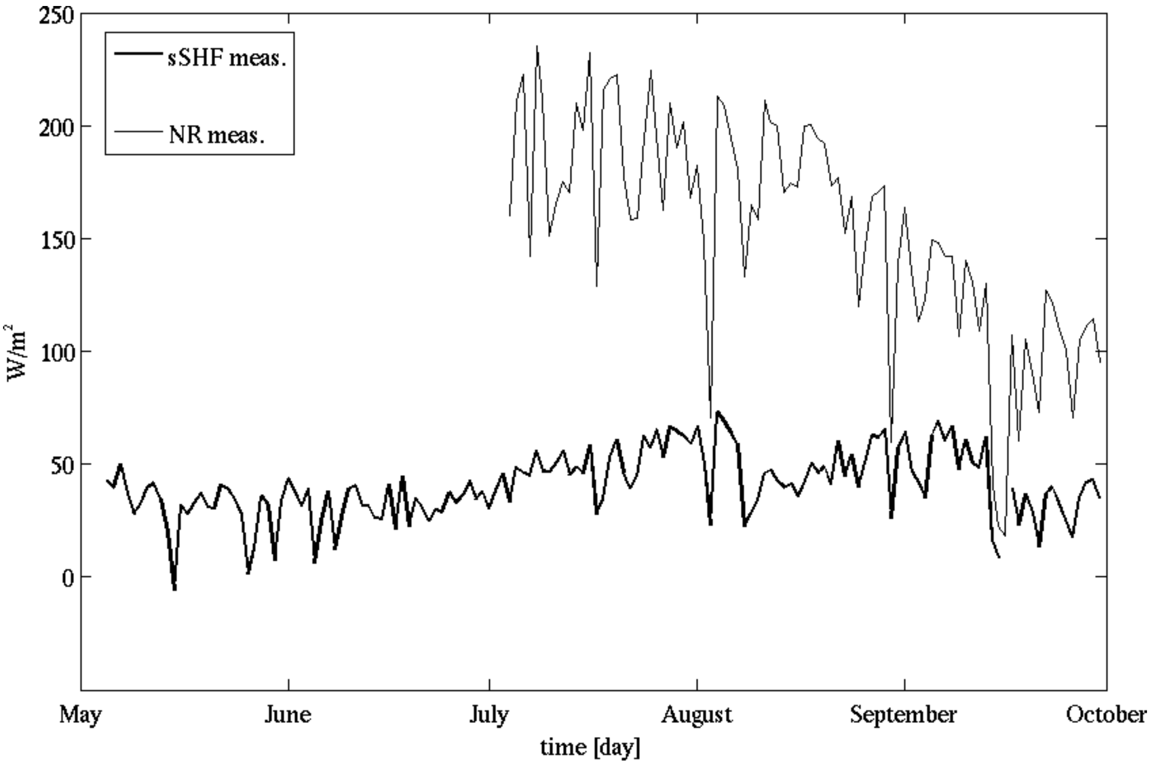


Figure 5 shows the measurements of the soil volumetric water content (SVWC) and the daily cumulated rainfall. The SVWC sensor was installed at 15 cm below the soil surface, but in mid July its depth was evaluated as 10 cm only, suggesting a consistent compaction of the soil above the sensor. The inspection of the data shows the rapid decrease of the SVWC, which falls below the wilting point (0.22 m^3 m^{-3} for this type of soil [18]) already at the beginning of June. Apart from three large peaks in occasion of relevant rainfalls (in mid June, mid July and—the largest—at the beginning of August), SVWC reached the minimum value in mid September. The steep decrease of the SVWC, both in general and after the larger rainfall episodes (as at the beginning of August or in mid September), seems to suggest two hypothesis: i) the ET processes are important, and ii) the infiltration rate is larger than expected for the silty clay loam soil type, for which the porosity is equal to 0.47 m^3 m^{-3} [18].

The soil temperature (ST), compared with air temperature measured at the screen height (Figure 6), underlines the reduction of the amplitude in the former with respect to the latter, especially during the cold episodes (whose frequency is about two per month), usually lasting less than one week. Also a small phase shift (2–3 days) is evident during the major episodes. Both behaviors are in agreement with the theory of the thermal wave propagation into the soil [22]. Moreover, it is possible to define the warm season using as marker the threshold of 20 °C for the soil temperature (chosen for its lower daily variability, if compared with the air temperature). Neglecting the 2-days period at the end of May, it started on May 18th and ended on September 13rd.

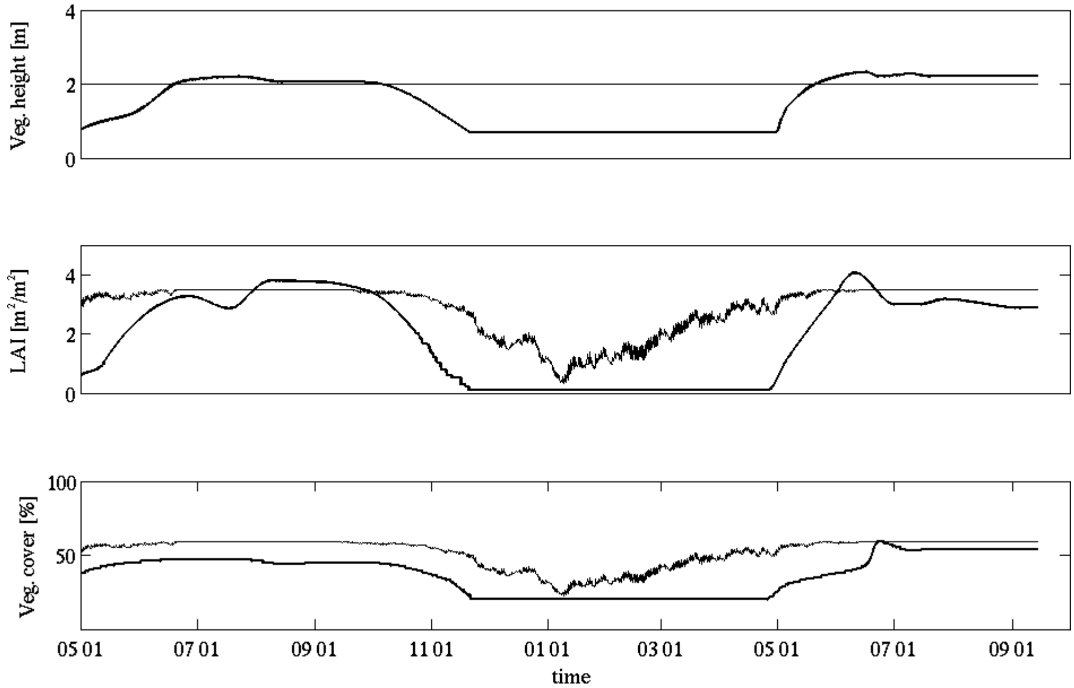
Figure 7 shows the net radiation (NR) and the “sonic” sensible heat flux (sSHF). The former, available since the beginning of July, was characterized by a general decreasing trend, well linked with the decrease of the GR (which, in turn, depends on the solar angle and on the day duration). NR daily oscillations are in phase with those of the sSHF, and on the long trend they went closer. The sSHF was slowly increasing from mid May to the beginning of August, and then, after a drop in the first week of August, again raised until September rainfall. Daily values of the ratio beetween the measured sSHF and NR were on average 28% during July and August and 41% in the first part of September (the driest period of the 2009 vegetative season). The latter value seems in partial contrast with the data of soil moisture (Figure 5), which showed a continuously decreasing of SVWC minima below the wilting point early June through mid September (*i.e.*, important ET processes).

3.2. Model Results

The two simulations, performed on a period covering both the 2008 and 2009 vegetative seasons, lasted from May 2008 until September 2009, data coinciding with the harvest time. The comparison between the two different initializations (control and experimental run) of the three vegetation parameters (LAI, vegetation cover and canopy height) is depicted in Figure 8. The thin lines represent the data of the new vegetation class (vineyard) inserted in the Wilson and Henderson-Sellers updated database, while the thick lines are based on the observations, as explained in subsection 2.4 The comparison among the three couple of curves in Figure 8 highlights that the experimental run parameters approach those of the control run only during the vegetative season, with an evident shift at its beginning, while during the late autumn and winter the model parameterizations underestimate consistently the observations. Moreover, the control run parameters were obviously unable to detect the lopping and thinning out of the vines, usually performed in June. Finally, the comparison between the observed time trends during 2008 and

2009 shows that the 2008 vegetative season started slightly earlier than the 2009 one, but due to the heat wave recorded in the 2009 and the contemporary cold wave recorded in the 2008 during late May (Figure 2), the growth rate during 2009 was faster than 2008, producing an anticipation of about one week in the phenologic phase.

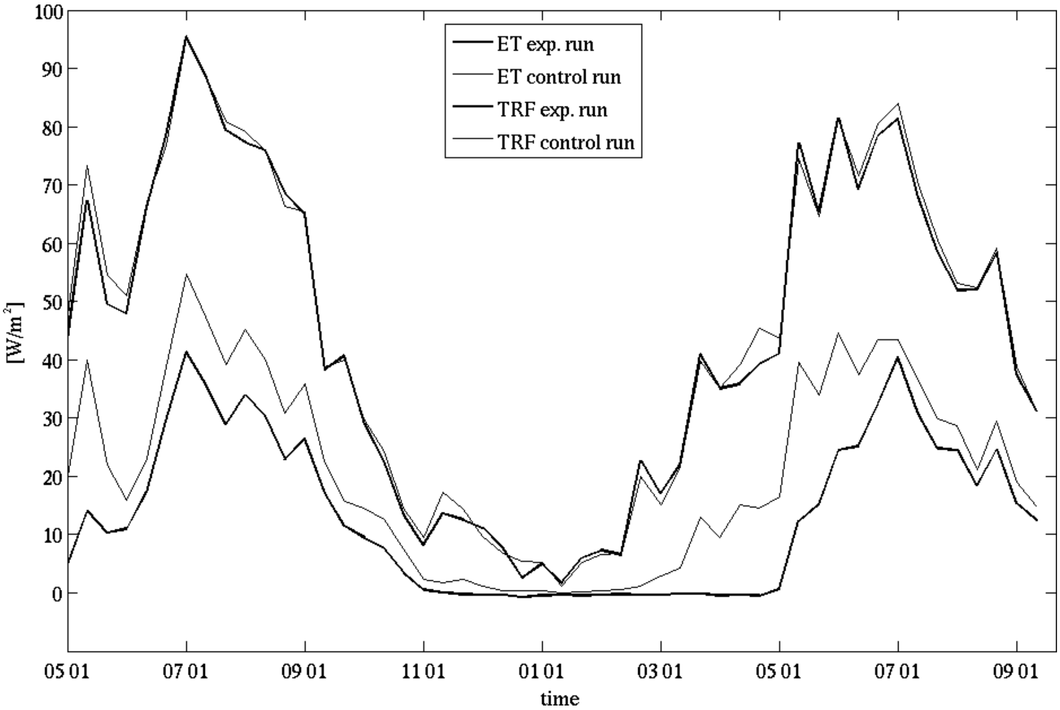
Figure 8. Initialization of vegetation height, LAI and vegetation cover in the experimental run (thick line) and in the control run (thin line) from May 2008 to September 2009.



As expected from Equation 3, the discrepancy between the vegetation boundary conditions, keeping unchanged the meteorological ones, influences the transpirative part of the ET (Figure 9) and, as a consequence, the hydrological balance. The values of the transpiration flux (hereafter TRF) in the control run are, on average, 15 Wm^{-2} higher (with peaks of 30 Wm^{-2}) than those of the experimental run during spring and summer. Comparing the two years of experimental run, the TRF during the 2009 spring is much larger than in the previous year, due to the heat wave recorded during May 2009. The behavior of TRF, as well as that of ET, is in good agreement with the observations of soil moisture, already below the wilting point on early june 2009.

The values of the latent heat flux, ET, which includes transpiration from canopy and evaporation from bare soil, are quite less sensitive to the vegetation boundary conditions, and show differences negligible in all seasons but in spring, where they reach at most 5 Wm^{-2}. The reason for such result can be arisen in the fact that the vegetation, from UTOPIA point of view, covers only partially the soil (the vegetation cover being always lower than 60%: see Figure 8), thus the contribution of the evaporation from bare soil is relevant (about 60% for the experimental run, and about 50% for the control run), reducing the dependence of ET from the vegetation cover, LAI and canopy height.

Figure 9. Evapotranspiration and transpiration fluxes (in Wm^{-2}) evaluated by UTOPIA in the experimental run (thick line) and in the control run (thin line) from May 2008 to September 2009. Data are averaged in decades (three per month).



The maximum ET during 2009 vegetative season is lower than that of 2008 in both simulations, with a difference of about 15 Wm^{-2} during the period July–August. These results seems to suggest that there was a progressive soil drying during the 2009 summer, more intense than in the previous year and, for this reason, the available energy was progressively mostly spent for heating the surface layer (increase in SHF and decrease of ET).

The data collected with the supplementary instruments installed for the 2009 campaign allowed preliminary quantitative validations of UTOPIA in the Barbera vineyard.

The influence of the two different vegetation parameterizations on the modeled NR, SHF, ST and SVWC is quite small, and the two simulations are almost superimposed, as shown in Figure 10 up to Figure 13 and from the accuracy indices in Table 2.

The observed NR was underestimated by about 50 Wm^{-2} in both simulations during the warmest months, and slightly less in September. The RRMSE values, equal to 30% on average, are in line with those proposed by Bellocchi *et al.* [23]. The underestimation of NR in this site can be considered as surprising, as it was never observed before in the simulations carried out using UTOPIA or LSPM, in any site. Two are the hypotheses currently advanced to explain this discrepancy. The first concerns the NR observation: Due to experimental technical requirements, the NR instrument was installed at the flank of the vineyards over the meadow, *i.e.*, in a different place with respect to the other sensors (installed within and above the vines). The second hypothesis, supported by the satisfactory value of the coefficient of determination r^2 (close to the unit) is that one or more calibration coefficients associated to vegetation or bare soil (namely, the albedo) were not accurately parameterized or the effects of the grass underlying the vines were not adequately taken into account.

Figure 10. Mean daily values of net radiation (in Wm^{-2}) during the 2009 vegetative season. The dashed line shows the measurements carried out on the flank of the vineyards, while the thick line refers to the experimental run and the thin line to the control run.

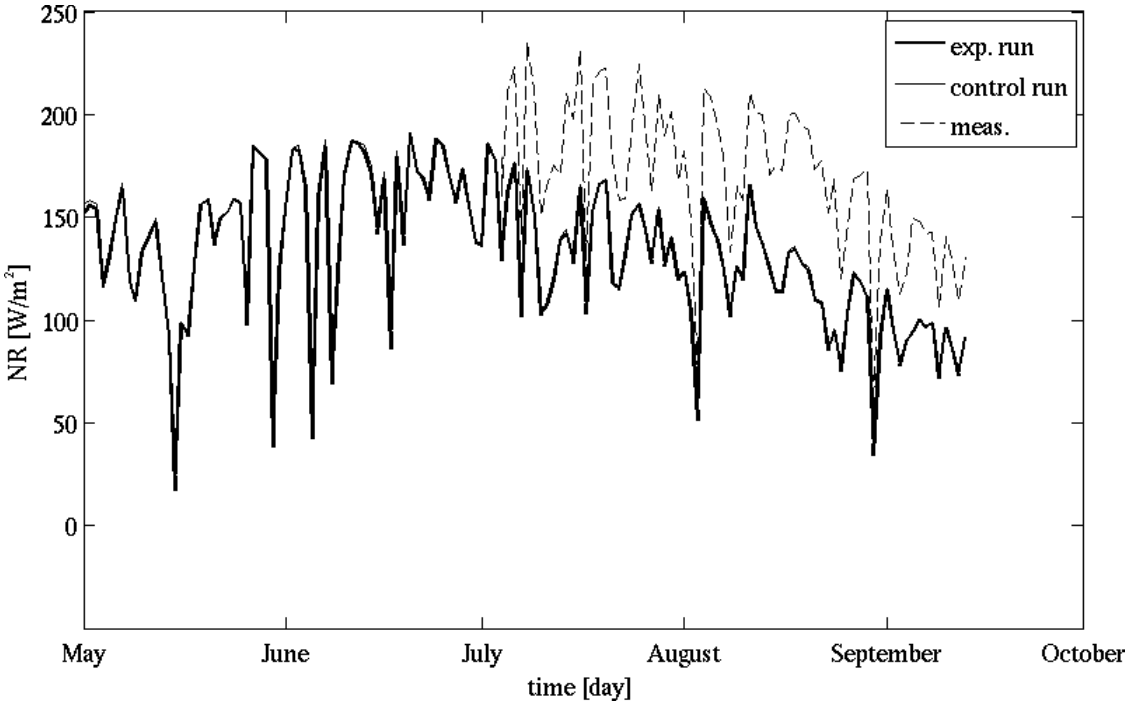


Figure 11. Mean daily values of sensible heat flux (in Wm^{-2}) during the 2009 vegetative season. The dashed line shows the values derived from the measurements carried out with the sonic anemometer above the vineyards, the thick line refers to the experimental and the thin line to the control run.

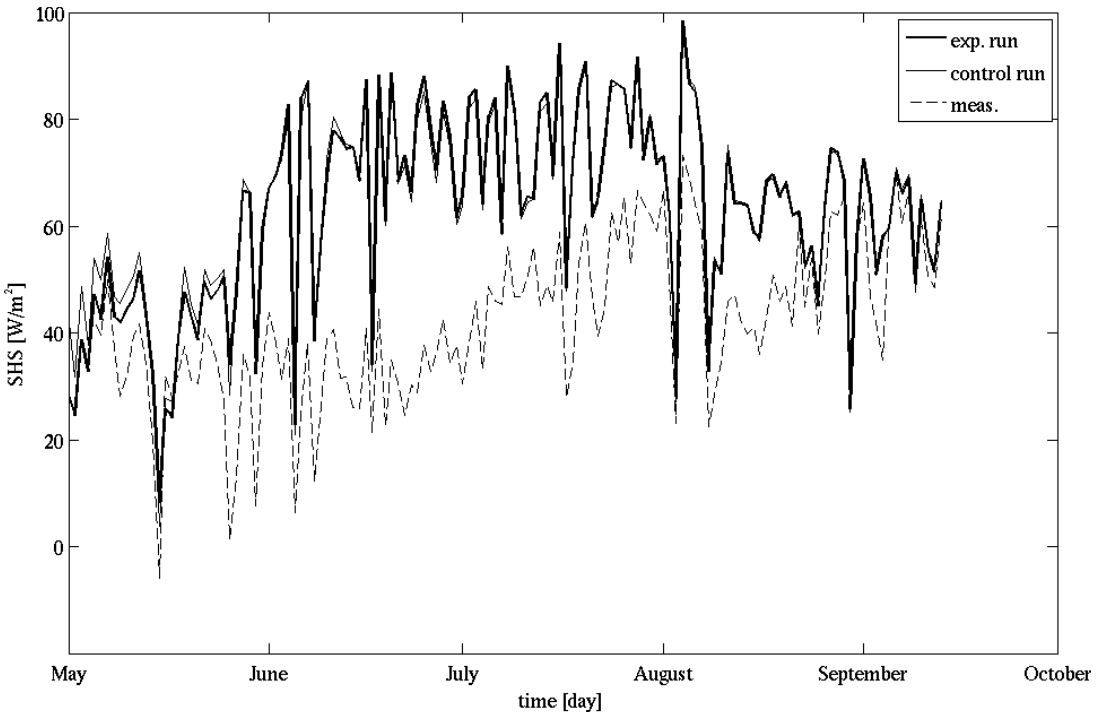


Figure 12. Mean daily values of soil relative humidity (*i.e.*, the volumetric soil water content normalized by the soil porosity) at 10 cm below the surface, during the 2009 vegetative season. The dashed line shows the measurements while the thick line refers to the experimental run and the thin line to the control run.

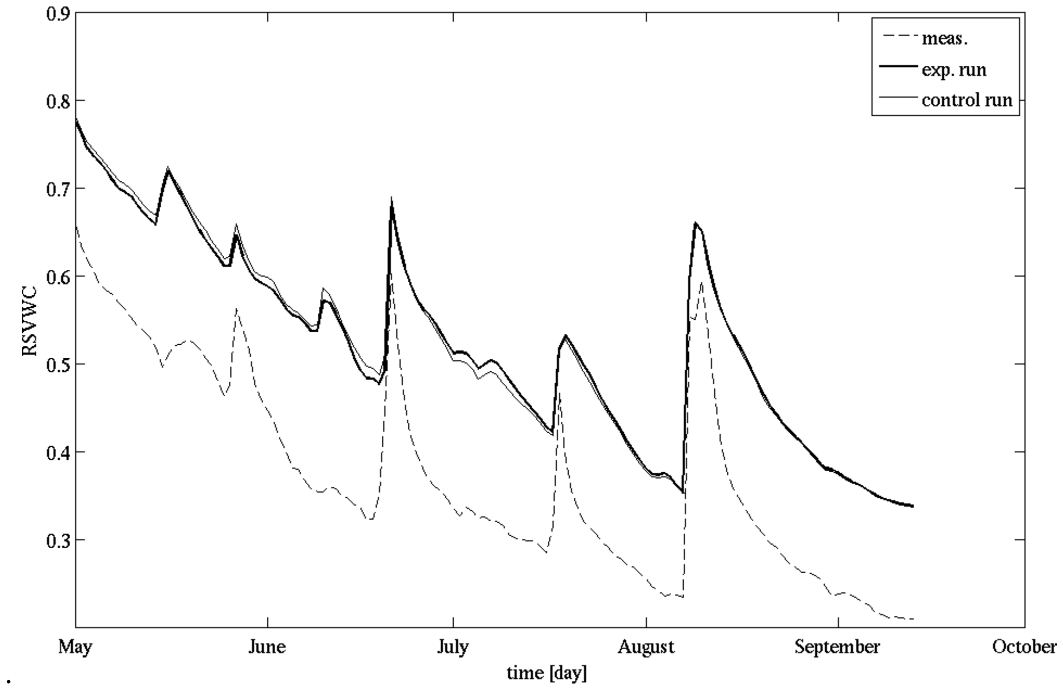


Figure 13. Mean daily value of soil temperature at 10 cm below the surface (in °C) during the 2009 vegetative season. The dashed line shows the measurements while the thick line refers to the experimental run and the thin line to the control run.

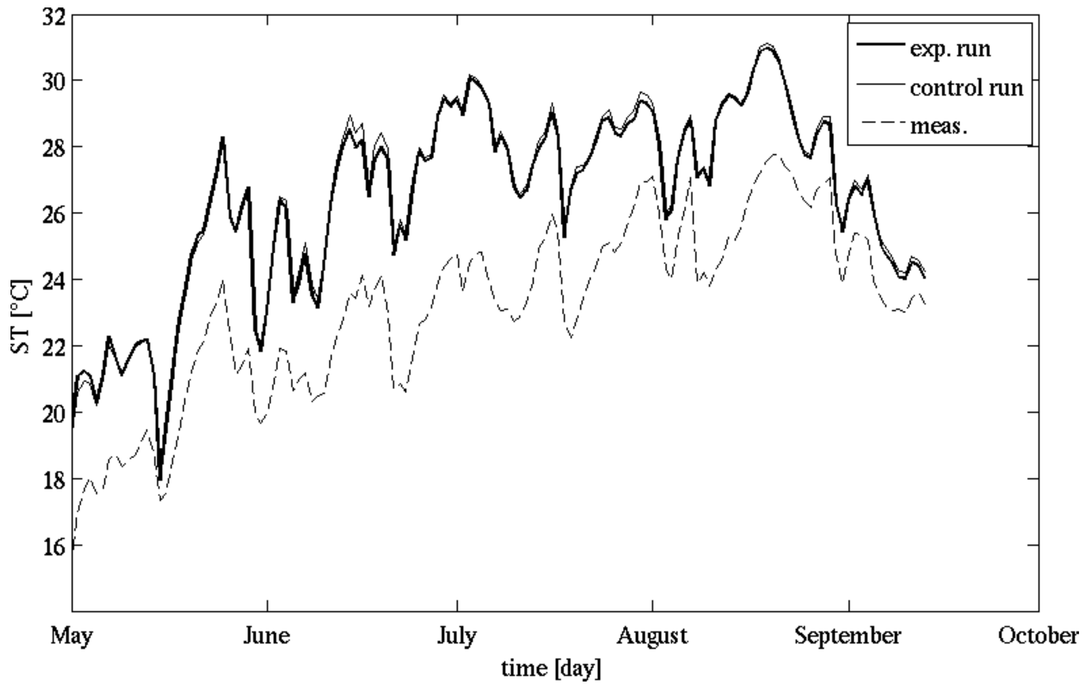


Table 2. Indices of agreement between measured and simulated daily values of NR, SHF, RVSWC and ST from the control and the experimental runs. For NR less data are available due to the late instrument installation.

	RRMSE (%)	r^2	total number of data
NR (control run)	30.20	0.90	72
NR (experimental run)	30.71	0.90	72
SHF (control run)	62.43	0.39	132
SHF (experimental run)	63.27	0.35	132
RVSWC (control run)	42.42	0.93	132
RVSWC (experimental run)	39.83	0.93	132
ST (control run)	15.56	0.83	132
ST (experimental run)	15.10	0.82	132

Also in the case of the modeled SHF, both simulations overestimate sSHF (see Figure 11) during the 2009 vegetative season, except in the beginning and end of the simulation (see in Table 2 the RRMSE). The difference is about 40 Wm^{-2} at the end of June and cannot be attributed to the difference between sSHF and SHF, quantifiable in this case in few Wm^{-2}. Besides the numerical values of the fluxes, also their trend is different, as showed by the low values of the r^2 coefficients. UTOPIA SHF show a jump of about 30 Wm^{-2} at the end of May, then its value remains almost constant until August, with some daily fluctuations. On the contrary, the measured sSHF reveals an almost regular growth during June and early July. RRMSE values attest the graphical analysis, though being lower than other found in model accuracy literature [24].

The differences between model and observations, for both NR and SHF variables, are reduced during rainy days (see Figure 1 and Figure 5).

When SHF underestimates sSHF, the ET is growing quickly (Figure 9), thus it may be not inconsistent to hypothesize that the variation of ET may affects sSHF but not SHF. Excepting for the hottest period, in May, August and September the differences among sSHF and SHF are small and can be considered of the same order of magnitude of the error associated with the measurements (quantifiable in 10–15 Wm^{-2}).

To compare the SVWC predicted by UTOPIA with the observed data (Figure 12), the measured SVWC was normalized with the soil porosity (equal to 0.47 $m^3\ m^{-3}$ for the silty clay loam soil) achieving the relative soil volumetric water content (RSVWC). The simulated values systematically overestimate the observations by 0.15–0.20 $m^3\ m^{-3}$ in absence of precipitation, while during and immediately after the precipitation events the overestimation is reduced to less than 0.1 $m^3\ m^{-3}$. The overestimation regards both control and experimental run, whose values differ between each other for less than 10% during late spring and almost coincide later. This behavior indicates that the overestimation is not caused by the uncorrect value of the vegetation parameters, thus it may be possible to conclude that the soil type below the upper 30 cm (not measured) had a different texture. In Figure 13 simulated and observed STs are shown. Even in this case, UTOPIA simulations overestimate almost systematically the observations, with differences slightly lower than 2 °C, irrespectively of rainy or dry weather. The reason for such discrepancy may arise from the too low vegetation cover values parameterized by UTOPIA simulations (see Figure 8).

For both ST and RSVCWC, despite the UTOPIA overestimations, emphasized by the RRMSE, the respective trends are well reproduced, as confirmed by the high values of the coefficient of determination (Table 2).

4. Conclusions

In this work, we present and analyze some preliminary results from a field experimental campaign, performed within a Barbera vineyard located in north-western Italy, and from simulations of energy and hydrological balance components carried out with the land surface model UTOPIA. The inspection of the data and the comparison among simulations and observations relative to 2008 and 2009 vegetative seasons allowed the evaluation of some key variables, in the specific environment of the vineyard. Moreover, additional variables suggested some issues in the interpretation of the measurements and in the procedures necessary to initialize the model.

The meteorological data showed that the 2009 season was warmer and drier than the 2008 and the last ten year climatic trend, notably concerning the spring. This behaviors had relevant consequences on the components of the energy and hydrological budgets and, in turn, on the vitality of the plants, whose phenologic phase was about one week anticipated in 2009. In particular, the highest radiation intensity during 2009 spring and summer (noticeably for the sensible heat flux data) resulted in an intense desiccation of the soil surface, and in the upper part of the root zone the SVWC was lower than the wilting point.

The analysis of the two UTOPIA simulations, using different methods to describe the vegetation growth in the seasons, revealed some relevant differences solely for the transpiration flux, which was not directly measured during the campaign. The indices of the model accuracy, evaluated using the available observations, showed no sensible differences between the two simulations for RN, SHF, RSVWC and ST. This analysis promote the more accurate vegetation variables description in UTOPIA.

The comparison between UTOPIA and experimental data evidenced some disagreements (*i.e.*, under- or over-estimations relative to the variable examined), suggesting on one hand, a further refinement of the vegetation description in the model, and on the other hand the need to have more specific measurements available in the experimental site.

In detail, some RRMSE were large (63% for the SHF and 40% for RSVWC on average), but comparable with other literature results ([23] and [24]). The best RRMSE values were obtained for NR (30%) and ST (15%). The satisfactory values of the coefficient of determination (ranging for every variable from 0.8 to 0.9, except 0.4 for SHF) suggested that UTOPIA can be considered able to reproduce the trends of this variables.

The simulations for the energy balance components allowed to draw some conclusions about the management of the field campaign as well. The agreement among the sSHF and modeled SHF in the last months of simulation was not similarly detected for the NR variable, supporting the conclusion that its experimental values did not reflect properly the processes within the vines. An additional experimental suggestion come from the observations of sonic sensible heat flux and soil moisture. Since these data variations not correlated between each other, it is tough task to find an unequivocal conclusion with actual means. The sSHF seems to suggest the presence of a soil surface able to produce a relevant transpiration (consistent with the modeled ET trend), while the SVWC shows that the root layer was exceeding the wilting point. In this case a measured ET would be crucial to validate the two dataset.

This work is important in order to stress some key issues to further develop in the upcoming activities. In synthesis, more care should be addressed on the calibration of some coefficients (*i.e.*, soil and vegetation albedo), on the selection of the instrument placements and on the inclusion in UTOPIA of the short grass partly covering the soil between the vine rows effects.

Despite the above mentioned need of further investigations, the data and simulation results presented are able to quantify the typical characteristics of the energy and hydrological balance components among the vineyards, and to assess, from a meteorological point of view, the typical values of the turbulent exchange fluxes, including the ET, during the vines vegetative seasons.

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