The estimation of the clear-sky effective PAR resources in a mountain area

L'estimation des ressources du PAR effectif en condition de "clear-sky" dans une région de montagne

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Summary

When evaluating the actual photosynthetically active radiation - PAR - resources available to plants the simple measurement or estimation of its total amount can lead to misleading interpretations, due to the frequent occurrence of radiation intensity above the light saturation threshold. In this case, besides the quantity of radiation, the use of other variables providing information on the temporal distribution of the resource (i. e. the insolation time) may be advisable. This work is an exploratory analysis of the effect of topography on the availability of PAR in an alpine viticultural region, the Aosta Valley, by the adoption of an index based on the summation over a given time period (in this specific case a day) of only the fraction of radiation effective for photosynthesis. Assuming clear-sky conditions, the resulting estimated maps widely differ from those of the total PAR, indicating spatial patterns closer to those of insolation time. The estimated ratios of "effective" to total PAR, assuming fully functional physiological conditions and fully developed canopies, vary from about 0.5 to 0.7 in the summer and from about 0.7 to 1 during the final ripening period; these values may be even lower in stress conditions.

Keywords: solar radiation, PAR, climate data, viticultural zoning

Introduction

The solar radiation plays a fundamental role in many physiological processes in plants both directly and indirectly. By influencing the environmental temperature, the solar radiation indirectly affects every biochemical reaction. Some specific ranges of its spectrum directly affect some key activities, like the photosynthesis (400 – 700 nm range, Photosynthetically Active Radiation = PAR), and many photomorphogenic responses, both cryptochrome and phytochrome mediated, including the metabolism of berry ripening (Shultz, 2000, Poni et al. 2007).

Due to its indirect effect on thermal resources and direct effect on photosynthesis and other fundamental physiological processes, the evaluation of the radiation resources is essential in whatever experimental study aiming to investigate the physiological responses of the grapevine to environmental factors, including viticultural zoning.

In a previous work the effect of the relief on the distribution of the clear-sky solar radiation (i.e. not taking into account the possible cloud cover) in a mountain area was explored by means of a mathematical model working on the Digital Elevation Model (DEM) of the investigated region (the Aosta Valley viticultural area); several variables describing different aspects of the solar radiation (its intensity and its daily duration) over different time periods where also evaluated (Mariani and Zecca, 2008). The estimated clear-sky PAR levels often largely exceed the light saturation threshold; moreover, the high brightness of the sky typical of the endo-alpine climate suggests that this condition may occur with a high frequency in the actual (real-sky) conditions. The available climatological data of the Aosta area confirm that during the fully developed vegetation period almost half of the time the sky is completely clear (table 1). Three important viticultural areas, each with different prevailing aspects were compared: the south facing slopes on the orographic left of the central part of the valley (called "adret"), the opposite slopes on the orographic right, facing towards N or NW (called "envers") and most of the lower part of the valley, where this turns to a N-S direction (Arnad-Montjovet area)(Fig. 1). These areas were found to be subject to very different radiation conditions:

1. high availability of solar radiation and relatively high presence of sun above the orographic horizon throughout the year ("adret");
2. low availability of solar radiation and relatively very short presence of sun above the orographic horizon throughout the year ("Arnad-Montjovet");
3. high variability of solar radiation and presence of sun above the orographic horizon throughout the year ("envers").

	Apr	May	Jun	Jul	Aug	Sept.	Oct	Year
Tenth of sky covered	4.6	6.4	4.1	3.9	4.9	3.8	4.5	4.4
Clear sky	12	7	14	16	12	15	13	160
Partly cloudy	9	6	9	12	8	9	9	98
Overcast	9	18	7	5	11	6	9	108

Table 1Climatology of cloud coverage during the vegetative period for Aosta station (Mennella, 1977).

These results suggested that the spatial and temporal distribution of solar energy is strongly influenced by topography, both on a yearly and on a daily scale. In the "envers" and Arnad-Montjovet area, during most of the growing season, a comparable amount of clear-sky PAR is distributed in substantially different daily insolation times (longer in the "envers"); hence, the amount of PAR alone often (i.e. when light saturation occurs) does not allow a correct evaluation of the expected physiological response. It may be more effective to evaluate the clear-sky PAR and Insolation Time (IT) at the same time, on the assumption that a longer insolation time may allow a more efficient use of a given amount of PAR, as a consequence of a probably lower loss of radiation due to light saturation, and also of the non linear response of photosynthesis to light.
The evaluation of the actual spatio-temporal distribution of PAR resources could be improved by the use of an index capable of summarizing (and improving) the radiation intensity and IT information, by summation of only the "effective" fraction of radiation. Ideally, this should be done knowing the actual physiological status of the plant in order to set a suitable light saturation threshold.

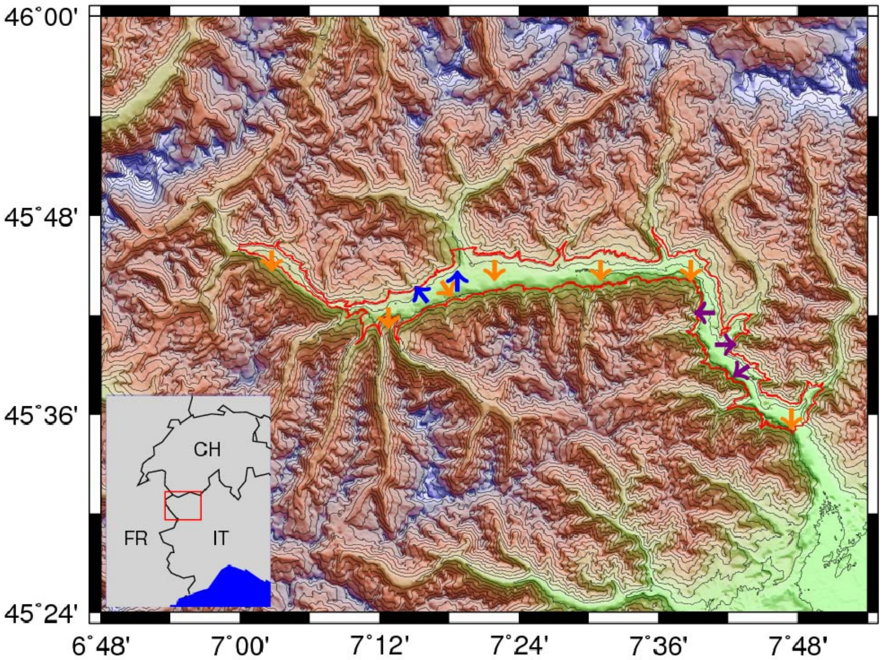

Figure 1 Topography of the Aosta Valley. The red line marks the Appellation of Origin area, which lies completely within the main valley. Three important viticultural areas were compared: the South facing slopes of the central Valley ("adret"), the North and North – East slopes ("envers"), the lower part of the valley, with a North – South orientation and slopes and alluvial fans characterized by various aspects

The aim of this work was to explore how such an index would represent the actual PAR resources of the studied region assuming clear-sky conditions and two different levels of photosynthetic efficiency (more specifically, two different light saturation thresholds).

While many investigations have been devoted to photosynthetic measurements on grapevine leaves, the evaluation of the photosynthetic activity at the whole canopy level is still little known. Peña and Tarara report light saturation thresholds of about 1200 µm m^{-2} s^{-1} and 800 µm m^{-2} s^{-1} for trellised vines under standard irrigation and under water stress respectively (Pena J. and Tarara J. 2004). These values correspond to PAR intensities of about 261 W m^{-2} and 174 W m^{-2}. Therefore, considering that PAR is roughly one half of global radiation, global irradiance values of 500 W m^{-2} and 350 W m^{-2} respectively were adopted as threshold for light saturation.

Materials and methods

The estimations were carried out using the clear-sky model proposed by the new digital European Solar Radiation Atlas (http://www.helioclim.net/esra, Rigollier et al., 2000). This model has been implemented in the module r.sun of the open source GIS software GRASS (Hofierka and Sudi, 2002). The r.sun module can be used for the computation of daily global radiation (as the sum of its three components direct, diffuse and reflected radiation) and insolation time raster maps or, alternatively, for the computation of irradiance raster maps at a given time. It takes into account the shadowing effect of the relief, the effect of air turbidity, the effect of ground albedo. For this work, the relief was described by a Digital Elevation Model with a grid of 75m x 75m (and its derived slope and aspect raster maps), the atmospheric turbidity was taken into account by a default monthly series of Linke coefficients for mountain environments (as proposed in the r.sun manual page), while for the albedo effect a default value of 0.2 was adopted. The absence of cloudiness was assumed (clear-sky conditions).

For the first day of each month of the fully developed vegetation period (June to October) the estimated global irradiance maps were computed with an hourly time step; from these, total and effective daily PAR were estimated. The total daily PAR was estimated by summation of 50% of each hourly global radiation; the effective daily PAR assuming non-stress conditions was computed by summation of: (i) hourly total PAR for values of estimated global irradiance under the 500 W m^{-2} threshold, (ii) 0.9 MJ m^{-2} (250 Wh m^{-2}) for values of estimated global irradiance above the 500 W m^{-2} threshold. The effective daily PAR assuming stress conditions was computed by the same procedure but applying a 0.63 MJ m^{-2} (175 Wh m^{-2}) hourly PAR threshold. Finally, raster maps of the percentages of effective PAR were computed.

Results and discussion

The maps of the estimated fractions of effective PAR (Fig 2) confirm that the light saturation occurs quite frequently in almost the whole considered region during the fully developed vegetation period. In absence of physiological stress during the summer only 50 – 70% of the total clear-sky PAR may be effective for photosynthetic activity; this percentage rise to 70 – 100% in the autumnal ripening period. With a light saturation threshold limited to 350 W m^{-2}, only half or less of the PAR may be considered effective during the summer months, 40 – 100% in the final ripening period.

Regarding the comparison among the three considered viticultural areas, the patterns of the effective PAR in clear-sky conditions (using both threshold levels) seem to describe a very different picture with respect to those of the total PAR: in addition to the drop of the levels, the maps in Fig. 3 show (i) an increased flattening of the values over the whole central area (including “adret” and “envers”), even in the late period, and (ii) significantly lower levels in the Arnad-Montjovet area (in the total PAR maps they are comparable and even higher than those of the “envers” area). The patterns closely resemble those of the insolation time maps (Mariani and Zecca, 2008), as expected. Thus this approach may succeed in describing the PAR resources without having to resort to more than one variable. Of course in order to obtain a reliable estimation, appropriate light saturation thresholds should be chosen; moreover, it should be noted that in many environments, including Aosta Valley, the clear-sky PAR estimation may not adequately represent the actual environmental conditions. Furthermore the global radiation information is still necessary in order to interpret other effects of light on the vine physiology, first of all the indirect effect on the thermal resources: the aspect gradient between North facing and South facing slopes in this region has been estimated in 2 – 2.5 °C.

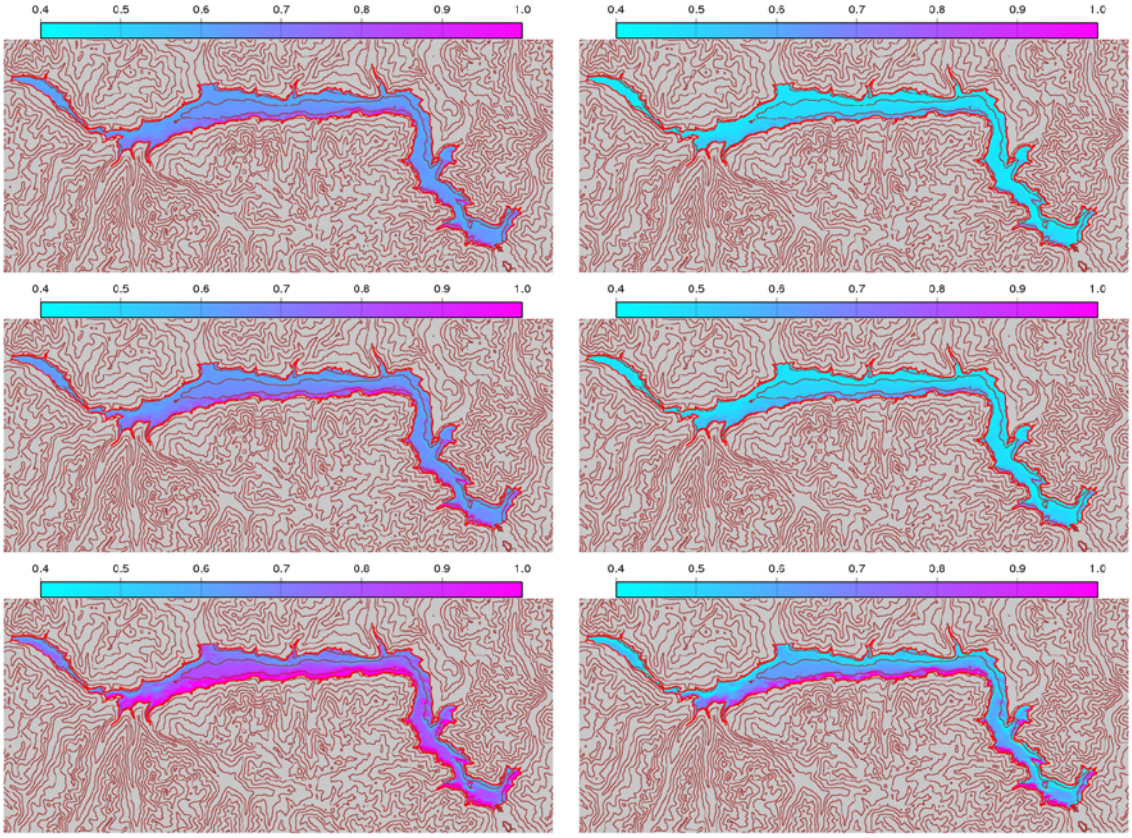

Figure 2 Estimated total PAR to effective PAR ratio assuming a global irradiance value of 500 W m^{-2} (left) and 350 W m^{-2} (right) as light saturation threshold, on June 1st, August 1st and October 1st (from top to bottom).

Conclusions

This work should be considered as an exploratory analysis aimed to better understand how the topography of a mountain area in an endo-alpine environment may affect the availability of photosynthetically active radiation, in order to select the most suitable variables or indexes which could represent the PAR resources.

The adoption of an index taking into account the physiological constraints of the grapevine in using the PAR may help in getting closer to a more realistic evaluation of the radiation resources actually available for photosynthesis. Moreover, this goal could be attained without the necessity of evaluating separately the intensity of the radiation and its daily duration, and with the added benefit of a more accurate estimation (provided that suitable thresholds are chosen and an accurate PAR estimation is achievable).

On the other hand, some possible drawbacks should be remarked. The estimation of the PAR resources following the framework proposed in this work does not take into account the variation of photosynthetic efficiency at the canopy level within the considered period due to changes in mean leaf age, nor the actual interception of the grapevine leaves, which is function of many factors like leaf orientation, shading effects of neighbouring leaves of rows and so on. Furthermore, the interaction between the indirect effect on temperature and the direct effect on photosynthesis is not considered: high levels of radiation can increase the temperature of canopy and this can be useful to enhance photosynthetic activity during cold days of spring and autumn, while, on the other hand, problems may arise due to thermal excesses during summer. In the studied case, the adopted default Linke turbidity coefficient series could lead to an overestimation of the clear-sky radiation; the determination of the actual monthly values, and of the daily variations, may result in a more reliable estimation. Finally, as already pointed out, the clear-sky assumption could often be inadequate to accurately estimate the actual radiation resources, and a real-sky estimation, when feasible, could be more appropriate (table 1 shows that in Aosta Valley the clear-sky condition occurs with a frequency of little less than 50% during the June to October period).

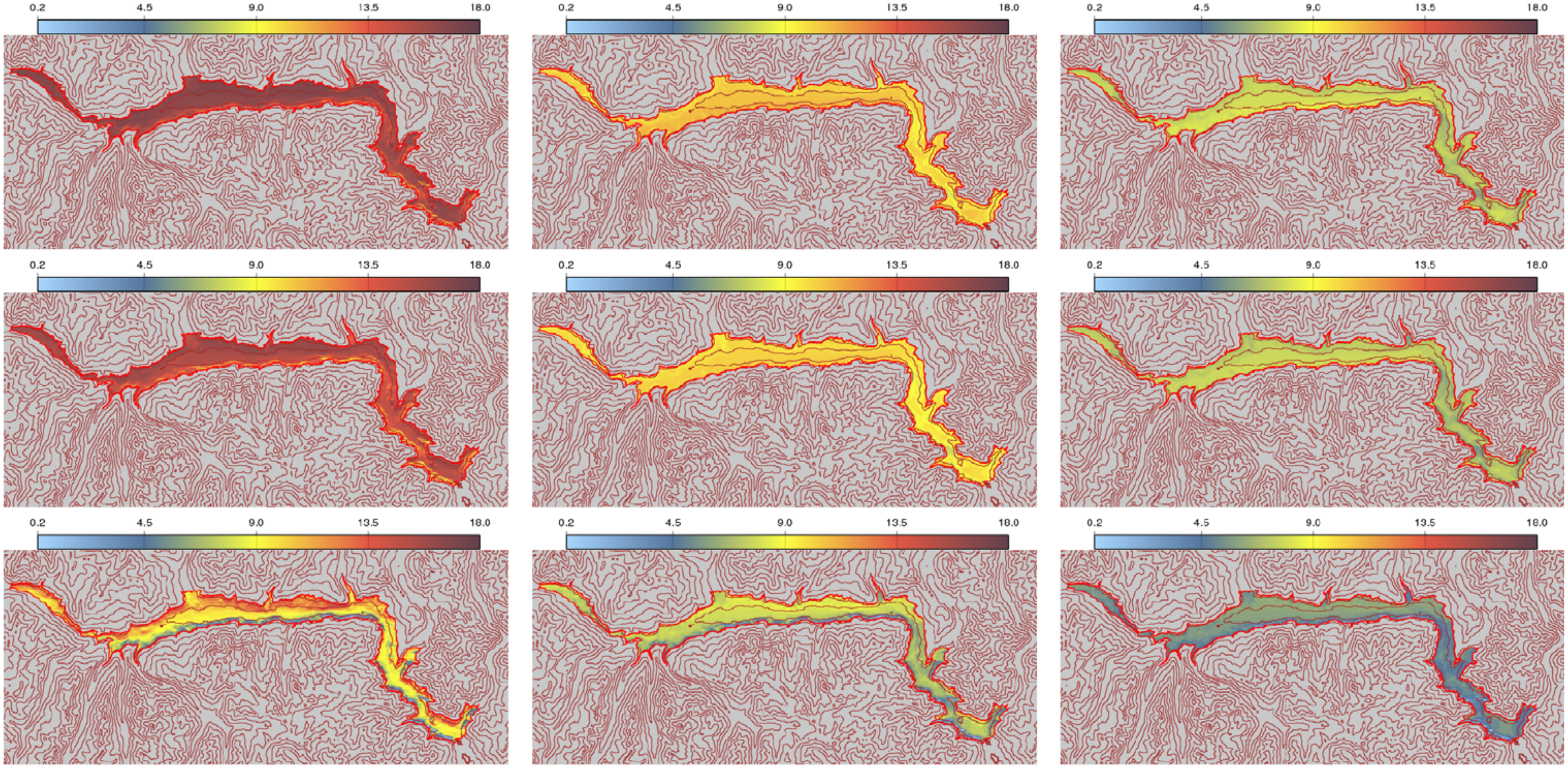

Figure 3 **Maps of estimated daily total PAR (left) and effective PAR assuming a global irradiance level of 500 W m^{-2} (middle) and 350 W m^{-2} (right) as light saturation threshold, on June 1st, August 1st and October 1st (from top to bottom). The PAR is expressed in MJ m^{-2} day^{-1}.**

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