

# Seasonal Dry Matter Production in Field-Grown Sangiovese and Montepulciano Grapevines (*Vitis vinifera* L.)

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## Abstract

Seasonal dry matter production of *Vitis vinifera* ‘Sangiovese’ and ‘Montepulciano’ cultivars was studied via destructive measurements in the field and by modeling daily carbon supply per vine. Carbon supply was obtained from the daily balance between photosynthesis and respiration rate, and accumulated as dry matter. The daily photosynthetic integral per vine was estimated from maximum net photosynthetic rate, photochemical efficiency, daily integral of light, day-length, canopy extinction coefficient and intercepted light. The daily respiration rate was estimated from the respiration rate and the dimension of the different organs (shoots, leaves, clusters). The trials were conducted in central Italy (Marche and Umbria), on spur-pruned and cordon-trained vines. Maximum photosynthetic rate and photochemical efficiency measurements showed that Montepulciano vines were more drought and high temperature tolerant in midsummer than Sangiovese vines, which had the highest photosynthetic efficiency under cooler temperatures in the first part of the growing season. After harvest, both cultivars showed similar photosynthetic behavior. All vine organs showed high respiration rate during the initial growth period. In Sangiovese, seasonal canopy dry matter accumulation, modeled by Stella software, fitted well to the effective dry weight accumulation obtained from destructive measures up to pre-harvest. Successively, the modeled supply increasingly exceeded the demand, thus allowing accumulation of reserves in old wood and roots. The seasonal dry matter production of grapevine can only be properly modeled through accurate measurements of photosynthetic efficiency and maximum photosynthetic rate, because their seasonal pattern during typical dry, warm Mediterranean summers is strongly variety-dependent and variety-specific.

## INTRODUCTION

Supply to demand balance is a basis for correlative studies in tree species, and can be directly used to determine optimal yield. Since seasonal integrals of dry matter production in the field are time consuming and expensive, mathematical models have been implemented for grapevines to study growth and development of some varieties (Gutierrez et al., 1985), demography of assimilation and allocation (Wermelinger et al., 1991; Vivin et al., 2002), and pruning and environmental factors (Lakso et al., 2000). In the present paper, the latter modeling approach was adapted to study two grapevine

cultivars, Sangiovese and Montepulciano (*Vitis vinifera* L.), widely cultivated in central Italy.

## MATERIALS AND METHODS

### Dry Matter Production Model

In the simplified model developed by Lakso and Johnson (1990) for apple, using the Stella dynamic simulation programming language with a daily step basis, the daily carbon supply per vine (DailyCBal,  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ) is determined from the difference between daily photosynthesis and daily respiration rate (Fig. 1). The dry matter accumulation (AccDM,  $\mu\text{g DM vine}^{-1}$ ) is calculated after converting DailyCBal by an estimated factor (CO<sub>2</sub>toDM).

The daily photosynthetic rate per unit of ground area (DailyPnRate,  $\mu\text{g CO}_2 \text{ m}^{-2} \text{ day}^{-1}$ ) is calculated and then multiplied by the surface area allotted per vine ( $\text{m}^2$  per vine,  $\text{m}^2$ ) to obtain the total amount of CO<sub>2</sub> assimilated per vine per day (DailyPnTot,  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ). The photosynthesis sub-model [1] was based on the equation of Charles-Edwards (1982) and modified by Lakso (1993):

$$[1] \text{ DailyPnRate} = \frac{(\text{PChemEff} * \text{Light} * \text{DayLgth} * \text{Pmax} * \text{LtInt})}{(\text{PChemEff} * \text{CanopyK} * \text{Light} + (\text{DayLgth} * \text{Pmax})) * \text{TeffDayPn}}$$

where: PChemEff = leaf photochemical efficiency ( $\mu\text{g CO}_2 \text{ Joule}^{-1}$ );  
 Light = daily integral of total radiation ( $\text{Joule m}^{-2} \text{ day}^{-1}$ );  
 DayLgth = daylength (s);  
 Pmax = rate of light saturated leaf photosynthesis ( $\text{mg CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ );  
 CanopyK = canopy light extinction coefficient;  
 LtInt = intercepted light (percentage of incident light);  
 TeffDayPn = temperature effect on photosynthesis (correction coefficient arises from an equation and variable from 0 to 1).

The daily respiration rate per vine [2] (DailyResp:  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ) is obtained by summing cluster (DayRCluster:  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ), shoot (DayRShoot:  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ), and leaf (DayRLeaf:  $\mu\text{g CO}_2 \text{ vine}^{-1} \text{ day}^{-1}$ ) respiration rates. Root respiration is not included in the model. The respiration sub-model [2], which includes leaves, clusters and shoots, is based on the exponential response of the respiration rate (R) to temperature, and expressed by:

$$[2] \quad R = a \cdot e^{k \cdot T}$$

where: a = R at T = 0 °C;  
 k = temperature coefficient of R (the slope of lnR versus T);  
 T = temperature in °C.

To obtain the whole respiration per vine, respiration rate is multiplied by the estimated dimension of the different organs, obtained from the destructive measurements taken in the field.

### Experimental Vineyard

A 5-year-old vineyard, located in Central Italy (Castelferretti, Ancona, latitude 43°40'N), on a southern-exposed hillside (40 m) was studied. Sangiovese (clone R4) and Montepulciano (clone R7) vines, grafted on 420 A, were spaced 1.0 m apart in the rows, and 2.5 m apart between the north-south oriented rows. A spur-pruned cordon was used as the training system and the bud load was 12 per vine (Fig. 2). Shoots were maintained

upright using two movable foliage wires. As soon as the shoots exceeded the height of the poles (1.95 m), mechanical topping was carried out. A few days later, lateral shoots were edged. The soil was deep, clay-loamy, and fertile. Minimum tillage was done between the rows, and herbicides were localized along the row. No irrigation was applied. Daily light intensity (Light), minimum and maximum temperature (TempMin and TempMax) and rainfall were measured by a local weather station (Fig. 3). Sangiovese shoot and cluster growth parameters (length, fresh and dry weights) were measured on a sample of 16 shoots every 15 days on different vines. The number of shoots and clusters per vine was counted before bloom.

### **Photosynthesis Sub-Model**

To obtain photochemical efficiency, the light-response curves were determined between 800 and 1000 during May-June, between 900 and 1100 in July-August, and from 1000 to noon in September-October, on clear sunny days. Well-expanded mature leaves were pre-conditioned for 30 minutes at increasing light levels using a different number of shading layers of a 33% sunlight absorption net. The net layers, from 0 to 8, were fixed on a plastic frame (30 × 20 cm) on the top of a 1.5 m pole in order to cover two leaves. Two replications per each shading level per variety were set and two readings per light level were carried out.

Net photosynthesis was measured using a portable open system (ADC-LCA4, UK). Apparent photochemical efficiency was determined from the rectilinear portion of the light response curve up to 160  $\mu\text{mol}$  (photons)  $\text{m}^{-2} \text{s}^{-1}$  of photosynthetic active radiation (PAR). This value was then divided by 0.85 (leaf absorbance) and 0.88 (loss due to Plexiglas in the chamber) to obtain effective photochemical efficiency (PChemEff). Maximum photosynthetic rate (Pmax) was determined at light saturation.

In the first part of the season, the intercepted light was estimated as a function of shoot growth and, after summer pruning, by the maximum value of 0.48.

Canopy K gradually varied from 0.140 after bud burst to a maximum of 0.328 in the middle of the season before green pruning and at the end of the season was reduced to 0.183. The maximum value was calculated using the empirical model of Oliveira and Santos (1995).

In the spring,  $\text{CO}_2$  was converted to dry matter using a factor of 0.5, which gradually increased up to 0.7 in the summer and autumn.

### **Seasonal Respiration Rate in Different Vine Organs**

The respiration rate in leaves, inflorescences, clusters and shoots was measured during the season by using an open system LCA-3 portable infrared gas analyzer (ADC, UK). These measurements were taken midmorning on four to five samples, as replicates. On each date, leaves, clusters and shoots from 12-year-old Sangiovese/Kober 5BB vineyard were enclosed in a leaf (PLC3N) and in a fruit chamber (PLC-3FM), respectively, and flushed for 4 to 8 minutes with ambient air at 500 ml/minute. In all measurements taken, the time needed to reach a steady state was between 2 and 6 minutes.

### **The Respiration Sub-Model**

In 2000 and 2001, the respiration rate of leaves, inflorescences, clusters, and shoots was measured in 4-year-old potted vines of Sangiovese/Kober 5BB at temperature of 10, 15, 20, 25, 30, 35 °C ( $\pm 0,8$  S.E.) using a 12  $\text{m}^3$  climatic chamber (Angelantoni Industria, Massa Martana, Italy). The temperature of the different vine organs was monitored using a mini-thermistor directly attached to the organs with a small strip of surgical tape. Within each temperature level, the time needed to reach the set temperature in vine organs was between 3 to 5 hours.

During the season, the coefficients a (intercept) and k (the slope of  $\ln R$  versus T) were calculated 5 times for the leaves, 3 times for the shoots, once for the inflorescences and twice in the clusters.

## RESULTS AND DISCUSSION

### Photosynthesis Sub-Model

In 2001, a prolonged period of drought from June to the end of August ended with heavy rainfall which continued to the first part of September (Fig. 3), and was then followed by a new dry period with warm temperatures to the end of October. Sangiovese grapevines showed a slightly earlier bud burst (about 1 week) in comparison to Montepulciano. The Sangiovese PChemEff (Fig. 4) was very high at the beginning of the season (Fig. 5). At the end of July and in August during the hot, dry days, Sangiovese showed a sharp decrease in PChemEff. A better acclimation to both drought and high temperatures was observed in Montepulciano vines, which reached the PChemEff maximum value in July. Consistently, Pmax in Sangiovese grapevines was highest in May (Fig. 6), and later decreased and reached the minimum at the end of August when the drought was severe. In September, when mild, humid conditions prevailed, a significant recovery of Pmax was observed, but Pmax decreased at the end of October. Therefore, Pmax was stably high even after harvest, with a small reduction likely due to leaf aging.

Montepulciano grapevines showed different behavior, suffering from the initial low spring temperature and exhibiting the highest value for Pmax in July. After this optimal period, the Pmax gradually decreased, probably due to leaf aging, without showing any drought or harvest interference. Leaf yellowing began very late in October in both varieties and leaf fall was finished by the end of November.

### Seasonal Respiration Rate in Grapevine Organs

Under dark conditions, all vine organs showed high respiration rate during the initial and rapid growth period, especially when cell division was rapid and cell enlargement was marked (Fig. 7-9). In the leaves, the maximum respiration rate occurred during the first 6 to 7 weeks after bud burst, followed by 14 to 15 weeks of nearly constant CO<sub>2</sub> respiration (from 60 to 70  $\mu\text{g CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ). Respiration then diminished due to senescing processes (Fig. 7).

From two weeks before flowering until two weeks after flowering, the respiration rate of inflorescences and clusters remained almost constant, ranging from 2.0 to 2.4 mg CO<sub>2</sub>/g fresh weight h<sup>-1</sup> (Fig. 8). Similar inflorescence respiration trends were found on different grape cultivars from 2 weeks before bloom until bloom (Blanke, 1990; Palliotti and Cartechini, 2001). Subsequently, CO<sub>2</sub> derived from respiration processes in the berry diminished up to 0.4 mg CO<sub>2</sub>/g fresh weight h<sup>-1</sup>. At midmorning, the shoots showed high levels of respiration during the 2 weeks after bud burst and progressively declining rates during the growing season (Fig. 9).

### Respiration Rate Sub-Model

The respiration rate in Sangiovese leaves, inflorescences, clusters and shoots increased as the temperature rose from 10°C to 35°C (data not shown). The coefficients, a and k, were calculated in the different vine organs during the growing season.

### Dry Matter Accumulation

Dry matter accumulation was compared in the Sangiovese vines, with shoot, leaf, and cluster demands (dry weight) obtained from destructive measurements (Fig. 10). The model prediction fitted the demand up to pre-harvest, and then increasingly exceeded it. This difference between the modeled dry matter supply and the measured demand from pre-harvest to leaf senescence probably was also able to cover the root demand which was not included in this study. Therefore, it can be concluded that these vines had a good vegetative and reproductive balance, and their eventual crop load could be increased.

Comparing the modeled supply of the two varieties, it is worth noting that Montepulciano grapevines were more drought and high temperature tolerant in mid-summer than Sangiovese which had the highest dry matter production during the first part of the season under cooler temperatures (Fig. 11). After harvest, both cultivars showed similar photosynthetic supply.

## CONCLUSIONS

The daily time step model implemented by Lakso and Johnson (1990) using Stella software, and successively modified for grapevine, was able to efficiently estimate the vine supply compared to actual demand (leaves + shoots + clusters dry weight accumulation) up to pre-harvest, then increasingly exceeded it, likely due to accumulation of reserves on old wood and roots which were neither included in the model nor in our study. The seasonal dry matter production of grapevine can only be properly modeled using accurate photosynthetic efficiency and maximum photosynthetic rate measurements, as their seasonal patterns during typical warm, dry Mediterranean summers are strongly variety-dependent and variety-specific.

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**Figures**

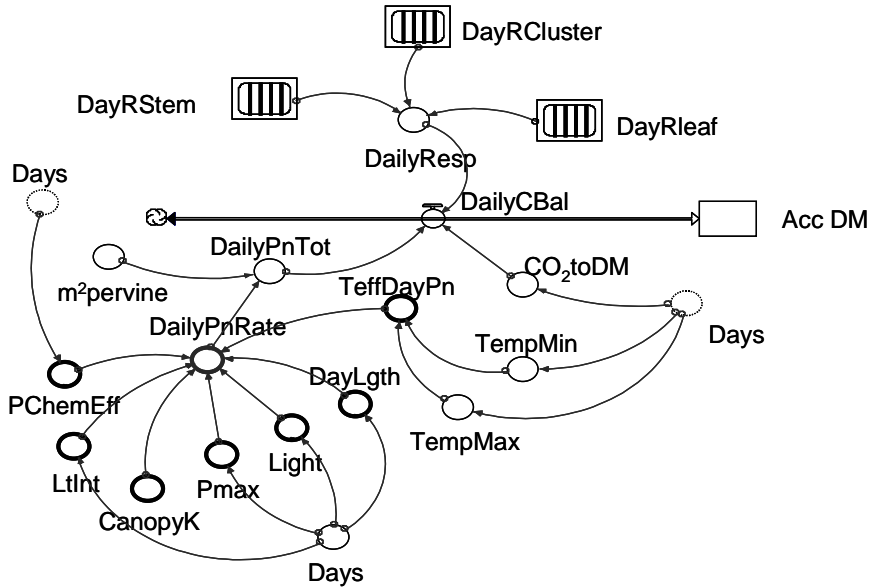


Fig. 1. The seasonal dry matter accumulation model was implemented in Stella dynamic simulation programming language (modified from Lakso 1993). Abbreviations are in the text.

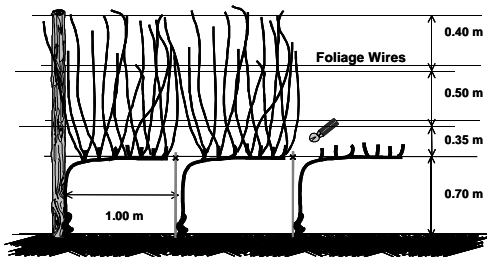


Fig. 2. Spur-pruned cordon with vertical shoots trained using movable foliage wires.

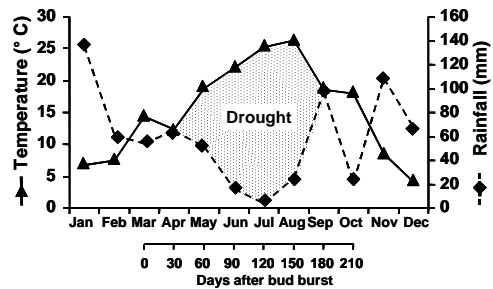


Fig. 3. Mean air temperature and rain-fall during the 2001 season.

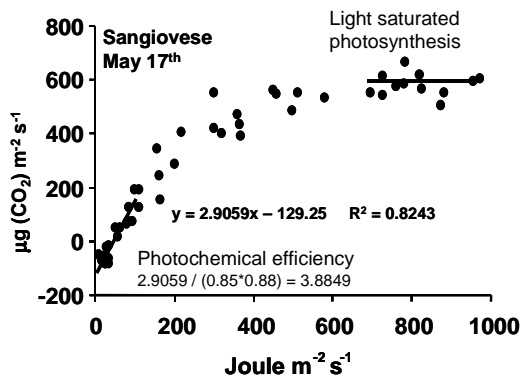


Fig. 4. Photosynthetic light response curve of Sangiovese leaves (May 17<sup>th</sup>).

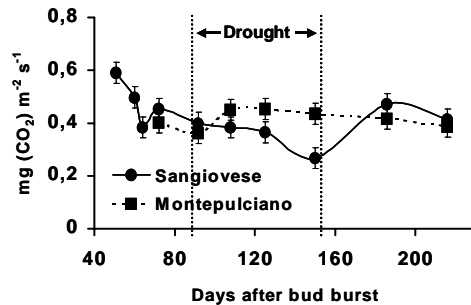


Fig. 5. Seasonal photochemical efficiency in Sangiovese and Montepulciano leaves.

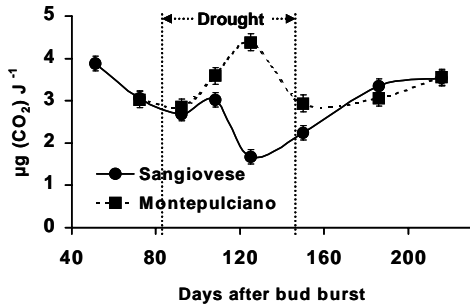


Fig. 6. Seasonal light saturated photosynthesis (Pmax) in Sangiovese and Montepulciano leaves.

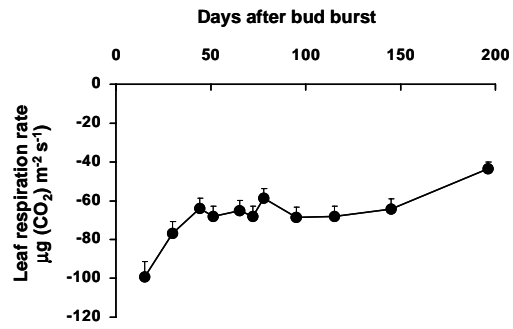


Fig. 7. Seasonal leaf respiration rate in Sangiovese vines.

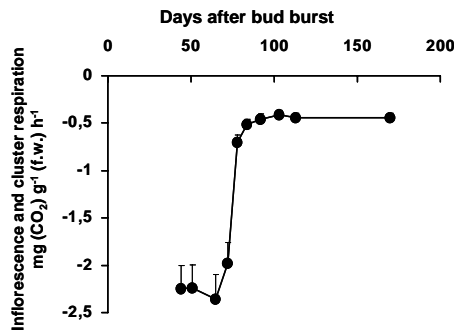


Fig. 8. Seasonal inflorescence and cluster respiration rate in Sangiovese vines.

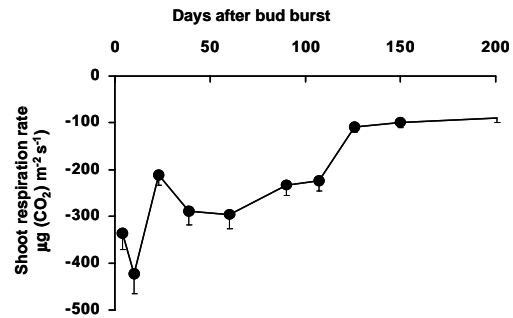


Fig. 9. Seasonal shoot respiration rate in Sangiovese vines.

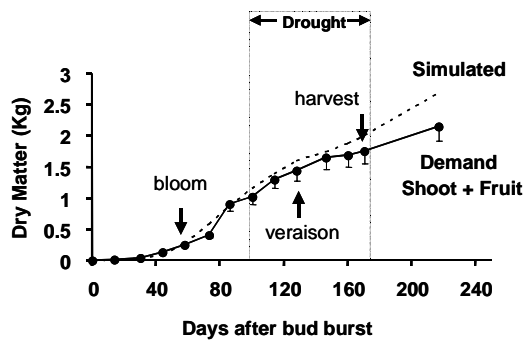


Fig. 10. Modelled dry matter accumulation in comparison with leaf, shoot and cluster demand in Sangiovese vines.

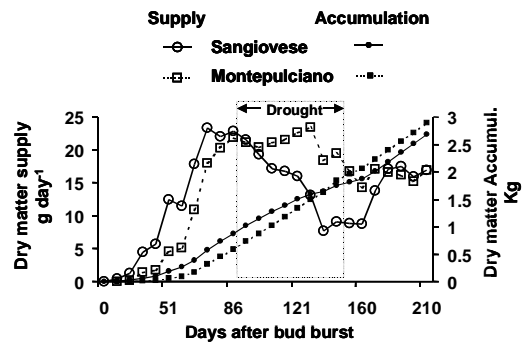


Fig. 11. Modelled dry matter supply and accumulation in Sangiovese and Montepulciano vines.