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A simple model for simulation of growth and development in grapevine (*Vitis vinifera* L.). II. Model validation

by

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Summary: A simple model for the simulation of growth and development of Sangiovese vines has been presented in a previous paper. In this paper the model is validated to examine whether the description of the physiological relationships in the model describe the growth of grapevine (cv. Sangiovese) realistically. Furthermore, the model was adapted and validated for the simulation of growth of another cultivar (cv. Cabernet Sauvignon). Comparisons of simulated and experimental data for both cultivars reveal that the model made good predictions of vine growth for the whole growing season.

Key words: simulation model, cv. Sangiovese, cv. Cabernet Sauvignon, growth, validation, application.

Introduction

A simple simulation model of grapevine growth and development was described and parameterised for cv. Sangiovese in a previous paper (BINDI *et al.* 1997). The model represents a hypothesis on growth and yield of grapevine. Model parameterisation was conducted on the basis of a single set of experimental data.

In this paper, model validation is performed by comparing model predicitions with field observations of grapevine growth in two subsequent years (1993 and 1994). Moreover the model is adapted for another cultivar (Cabernet Sauvignon), and then validated using two years of field observation. Finally, possible applications of the model are demonstrated briefly.

Material and methods

Experiments: From 1992 to 1994 two experiments were made to develop and validate the model described in the previous paper for Sangiovese and Cabernet Sauvignon. In particular, a vineyard with 20-year-old Sangiovese grapevines at the Mondeggi-Lappeggi farm and a vineyard with 25-year-old Cabernet Sauvignon grapevines at the Santa Cristina farm in the Chianti region, Italy. The soils were: a clay loam (volumetric water content of ca. 0.4 cm^3 cm^{-3}) at the Mondeggi-Lappeggi farm and a clay (volumetric water content of ca. 0.5 cm^3 cm^{-3}) at the Santa Cristina farm.

Viticultural practices, sampling techniques and recording of weather data were identical with those described in part I (BINDI *et al.* 1977).

Model adaptation and testing: To simulate growth and yield of Cabernet Sauvignon vines adaptations of shoot leaf area, radiation use efficiency and fruit biomass index were made using values obtained from the experiment at the Santa Cristina farm in 1992 (Tab. 1).

The model was tested in two ways: validation in which model predictions are compared with field observations, and sensitivity analyses which test how responsive the model is to changes in certain variables.

Table 1

Values of variables for cv. Cabernet Sauvignon (for details see Part I: Fig. 1, Tab. 1 (BINDI *et al.* 1997))

Variables	Description	Values
d, f	Coefficients in SLA equation	5.39, 2.06
EFF	Radiation use efficiency	0.691 g MJ^{-1}
SLOPE	Rate of change in FBI	0.00328 d^{-1}

SLA: shoot leaf area.
FBI: fruit biomass index.

Model validation was made comparing model performance with independent experimental data obtained from field trials in 1993 and 1994. These data were not used to build and calibrate the model. Daily values of minimum and maximum temperature and global solar radiation for the two years were used to simulate crop growth and yield. Using the 1992 field data, all parameters defining crop characteristics were held constant for the validation.

Sensitivity analysis of simulated total and fruit dry matter production to changes of weather factors was done in 1993 and 1994. Throughout each season, daily mean temperatures and solar radiation were changed by -20, -10, +10 or +20 %.

Goodness-of-fit: A wide range of statistical techniques has been proposed for model validation. No single combination of validation tests is applicable across

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the diverse range of models. In this paper both deviance measures and statistical tests were used to evaluate the goodness-of-fit of the models to the observed data.

Deviance measures: The average deviation of the simulated values from the measured values was evaluated calculating the mean bias error (MBE) and mean bias percent error (MB%E) according to MAYER and BUTLET (1993):

$$MBE = \frac{\sum_{i=1}^{n} xsim_i - xobs_i}{N} \qquad MB\%E = \frac{100 \cdot MBE}{xobs_i}$$

where N is the number of observations, $xsim_i$ is the *ith* simulated value, $xobs_i$ is the *ith* observed value. A positive value of MBE and MB%E indicates that, on average, the model overestimates a value with respect to that observed and *vice versa*. To measure the variation of the simulated values around the observed values the mean absolute error (MAE) and mean absolute percent error (MA%E) were calculated as proposed by MAYER and BUTLET (1993):

$$MAE = \frac{\sum_{i=1}^{n} \left| xsim_i - xobs_i \right|}{N} \qquad MA\%E = \frac{100 \cdot MAE}{\left| xobs_i \right|}$$

Statistical tests: The paried *t*-test, the linear regression analysis, and the modelling efficiency (EF) were used for model validation. The EF was defined as proposed by LOAGUE and GREEN (1991):

$$EF = \Sigma \left(xsim_i - xobs_i \right)^2 / \Sigma \left(xsim_i - \bar{x}obs \right)^2$$

where $\bar{x}obs$ is the observed mean. EF can range between 1 and negative infinity. EF values close to one indicate a "near perfect fit"; while EF < 0 indicate a "bad fit".

Results and Discussion

In Fig. 1 a-h the simulated dry matter production of the total biomass (i.e. shoots, leaves and clusters) and fruit is presented together with the corresponding field data. Obviously the model provides good estimates of both crop components. In addition the statistics confirm the visual appraisal (Tab. 2). Low deviance measures are obtained, with MBEs ranging from -2.46 to 58.23 and MAEs from 40.82 to 242.39 g per vine, and MB%E and MA%E varying from -0.7 to 2.7 % and from 9.9 to 11.8 %, respectively, depending on the cultivar and the crop component. The paired *t*-tests are not significant, and both R^2 and EF are quite good. Also, the individual *t*-tests of slopes against one and intercept against zero are not significant.

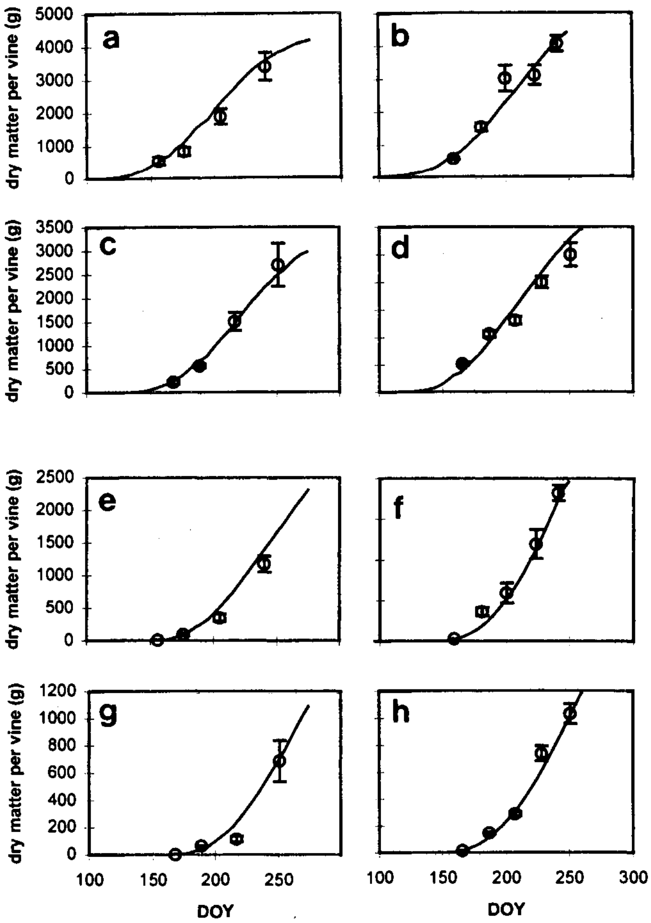

Fig. 1: Simulated total biomass (**a-d**) and fruit (**e-h**) dry matter (g per vine) of cv. Sangiovese (**a-b**; **e-f**) and cv. Cabernet Sauvignon (**c-d**; **g-h**) in 1993 (**a, c, e, g**) and 1994 (**b, d, f, h**). Observed values of crop components and standard errors are also reported. DOY = day of year.

Table 2

Statistical measures of validation

Cultivar/ Plant component	MBE	MB%E	MAE	MA%E	Paired *t*-test	R^2	Slope[a]	Intercept[b]	Modelling efficiency
	Deviance measures					Linear regression			
Sangiovese									
Fruit dry matter	1.93	0.2	78.83	9.9	-0.05^{ns}	0.979**	1.007^{ns}	-3.701^{ns}	0.978
Total dry matter	58.23	2.4	242.39	10.2	-0.57^{ns}	0.948**	0.978^{ns}	108.31^{ns}	0.945
Cabernet Sauvignon									
Fruit dry matter	-2.46	-0.7	40.82	11.8	0.11^{ns}	0.971**	0.942^{ns}	17.749^{ns}	0.970
Total dry matter	38.90	2.7	151.03	10.6	-0.66^{ns}	0.965**	1.030^{ns}	-3.673^{ns}	0.958

[a] *t*-test for slope = 1; [b] *t*-test for intercept = 0. ns not significant; ** P < 0.01.

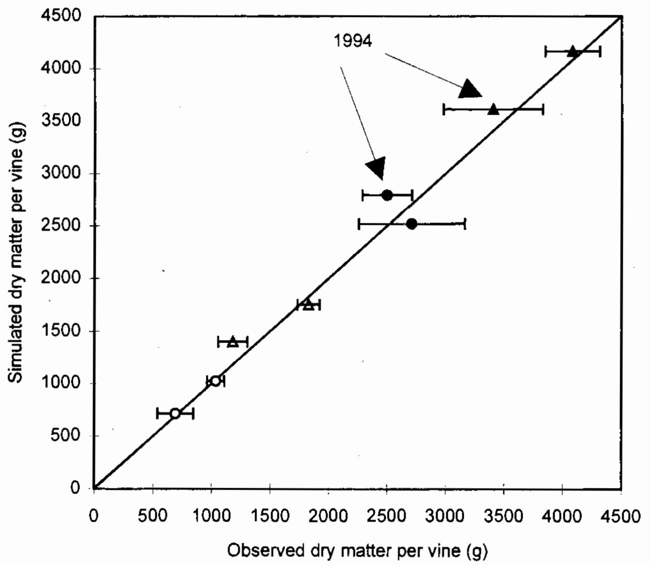

Fig. 2: Relationship between simulated and observed dry matter production. Total biomass (filled symbols) and fruit (opened symbols) of Sangiovese (Δ) and Cabernet-Sauvignon (**O**) vines.

Although the dynamic of both crop components was simulated satisfactorily, differences existed at the end of the growing season especially between the total biomass of the simulated and observed crops (Fig. 2). In particular in 1994, the model overpredicted biomass accumulation rate in the late season (Fig. 1 b, d). Since the unfavourable environment in this year (higher temperature and lower rainfall, Fig. 3) could have caused the crop to suffer from drought at the middle of the season, these differences may result from a lower rate of leaf extension (Fig. 4). With the incorporation of a water balance sub-model, which is currently developed, we anticipate that the model will simulate the biomass accumulation more accurately throughout the season. Differences in simulated and observed fruit production are less evident (Fig. 1 e-h). This could be explained by a higher sink strength of fruit for photosynthates compared to vegetative parts (Sartorius 1969; Ho *et al.*

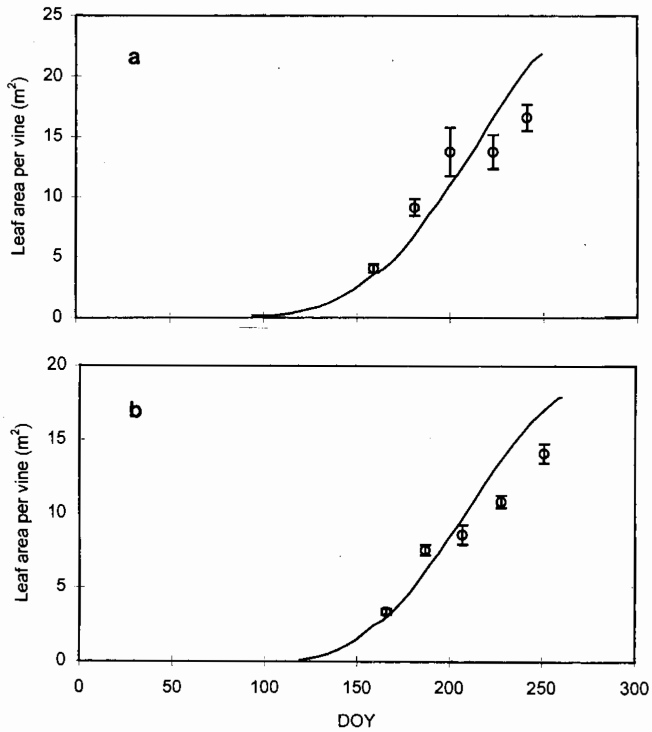

Fig. 4: Simulated leaf area (m^2 per vine) of cv. Sangiovese (**a**) and cv. Cabernet Sauvignon (**b**) in 1994. Observed values etc. see Fig. 1. DOY = day of year.

1989). This priority allows fruit growth to proceed at the expense of vegetative growth. In the model this priority of fruit growth is introduced by assuming a constant linear increase in the fruit biomass index (Bindi *et al.* 1996 a).

Results of the sensitivity test indicate that alterations of radiation have large influences on simulated biomass and yield (Tab. 3). Changing solar irradiance resulted directly in changes of fruit and biomass dry matter (from -19 to 20 %). On the other hand, higher temperatures depressed yield by accelerating crop development. However, at the same time higher temperatures stimulated photosynthetic activity thus limiting or compensating yield re-

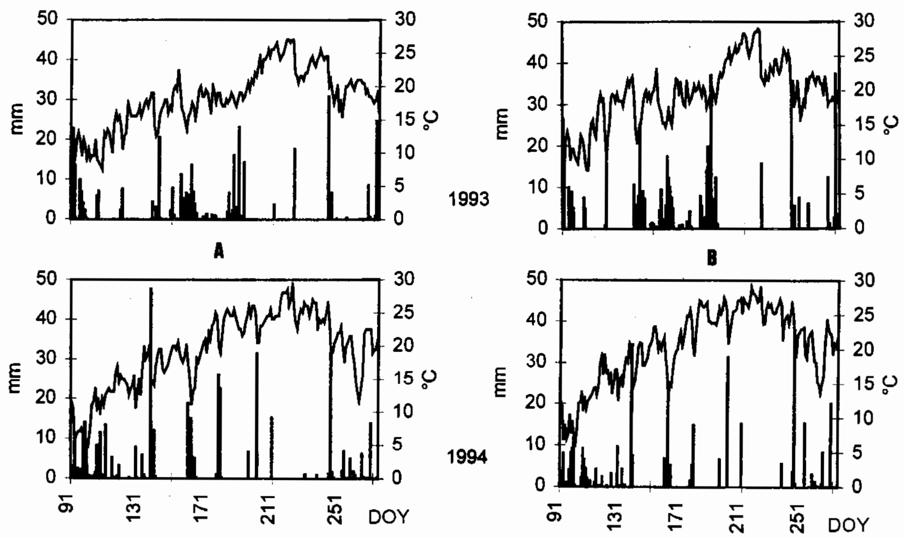

Fig. 3: Pattern of daily mean air temperature and rainfall (bars) in 1993 and 1994 at the Mondeggi-Lappeggi (**A**) and the Santa Cristina (**B**) farms. DOY = day of year.

Table 3

Dry matter of fruit and total biomass as affected by weather factors

Cultivar/ Year	Changes (%)		Dry matter per vine (g) Fruit	Total biomass
Sangiovese				
1993	Temperature			
		-20	2363	4163
		-10	2097	4294
		0	2229	4466
		10	2359	4642
		20	2429	4729
	Radiation			
		-20	1783	3573
		-10	2006	4019
		0	2229	4466
		10	2451	4913
		20	2674	5359
1994	Temperature			
		-20	1691	3951
		-10	1784	4117
		0	1896	4295
		10	2055	4461
		20	2176	4598
	Radiation			
		-10	1707	3866
		-20	1517	3436
		0	1896	4295
		10	2086	4725
		20	2276	5154
Cabernet Sauvignon				
1993	Temperature			
		-20	1094	2608
		-10	1047	2691
		0	1071	2768
		10	1149	2854
		20	1179	2903
	Radiation			
		-20	857	2214
		-10	964	2491
		0	1071	2768
		10	1178	3045
		20	1285	3321
1994	Temperature			
		-20	1120	2819
		-10	1205	2958
		0	1206	3024
		10	1241	3081
		20	1271	3125
	Radiation			
		-20	965	2419
		-10	1086	2721
		0	1206	3024
		10	1327	3326
		20	1448	3629

duction due to accelerated crop development. Results of these double and opposite effects were that alterations of temperature had smaller influences than solar radiation on simulated final fruit and biomass dry matter (from -11 to +15 %).

Conclusions

The model performed rather well when used to simulate growth of grapevine of two varieties and years. It accurately estimated the time courses of total and fruit dry matter production, even considering a slight tendency to overestimate total biomass accumulation in the late season. This could be overcome by introducing a water balance submodel.

Hence, calibrated for a given situation, the model can be of value in many applications. It may be used in combination with models attempting to predict the occurrence of fungal infection, to quantify the impact of disease damages on grapevine yield (BINDI *et al.* 1996 a) or to determine the time schedule of spraying fungicides with the aim to avoid unnecessary spraying. The model can also be used to explore effects of climatic changes, e.g. increases of CO_2 concentration on yield and yield variability, helping the breeders to anticipate future requirements (BINDI *et al.* 1996 b).

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