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Max Rives

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Vigour, pruning, cropping in the grapevine (*Vitis vinifera* L.). III. Examining the three-year production cycle

Max RIVES*

INRA, Station de Recherches de Viticulture, B.P. 81, 33883 Villenave d'Ornon, France

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Abstract – An experiment using plants obtained from cuttings and showing a range of mildew damage was set up to study the interrelations between various traits related to the accumulation of carbohydrate reserves and yield. A technique of progressive regression was used to analyse these relations. This is the first time that the 3-year cycle leading to a crop in the grapevine has been investigated in isolation.

grapevine / pruning / vigour/ yield / progressive multiple regression

Résumé – **Vigueur, taille, rendement chez la vigne (*Vitis vinifera* L.). III. Étude du cycle de 3 ans menant à la production.** Un essai utilisant des plantes obtenues à partir de boutures et présentant une gamme de dommages causés par le mildiou, donc de vigueur potentielle, a été utilisé pour étudier les interrelations entre les divers caractères associés à l'accumulation de réserves de glucides et au rendement. La technique de la régression progressive a été utilisée pour les analyser. Pour la première fois, le cycle de trois ans conduisant à du raisin récolté a ainsi pu être étudié à l'état isolé.

vigne / vigueur / taille / production / régression multiple progressive

1. Introduction

Both the literature review and the results of experiments on pruning and fertility provide indi-

rect evidence on the prevalence of a 3-year cycle in the grapevine. We made use of a phytopathological experiment, aimed at producing a continuous range of downy mildew infestation and infection, as a tool in testing the efficiency of

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* Correspondence and reprints: 33 rue des Mésanges, 30400 Villeneuve-lez-Avignon, France
rives@interlog.fr

anti-mildew chemicals. This provided a continuous range of damage intensity in the plants, thus yielding plants that hypothetically would have a continuous range of carbohydrate accumulation. The differences should be reflected in the 2 following years if the hypothesis of the 3-year cycle was correct.

2. Materials and methods

2.1. Experimental layout

Beginning in 1967, a trial was set up in the form of cuttings of Cabernet-Sauvignon [3]. In 1968, the rooted cuttings were left in place, and thinned to keep 5 rows of 48 plants. Distance between rows was 2.20 m, and between plants 0.35 to 0.60 m. Each row constituted a block of 8 plots of 6 plants.

The initial purpose of the trial was to try out a new system for testing fungicides against mildew (*Peronospora viticola*). To this effect, a water mist spray was applied to half the trial (no randomisation) with a plastic screen between the 2 parts, in order to protect the non-sprayed part of the trial from drifting water mist. First intermittently with activation from a sensor to keep the leaves wet, then in a continuous manner, the water mist provided an ideal environment for mildew infestation. It was fully efficient in inducing an intense early attack. Three fungicide treatments were used in addition to the untreated control: Bordeaux mixture at 0.5% and 2.0%, Maneb at 280 g AM per hl. Eight sprayings were made from July 3 to September 27, 1968.

The plant pathology results were fully satisfactory; the various treatments applied provided a progressive scale of damage, thus showing that water mist spraying could provide a favourable environment for mildew infestation, whatever the natural conditions during the year. These results have been published separately.

The scale of damage obtained through the combination of water mist and differentially efficient fungicide sprays suggested that it might be worthwhile to observe the after-effects of the damage on

the growth and development of the plants during the following years. As will be seen, this trial made it possible to observe in isolation one 3-year cycle leading to the formation of a crop, without any interaction with other ongoing cycles, as would take place in an adult plant.

2.2. Traits assessed

The following traits were observed:

N was the proportion of the leaf area covered with mildew spots, scored 1 (no spot) to 11 (all leaves destroyed) according to Horsfall and Barratt [1] on 50 randomly harvested leaves at a uniform level, on both sides of the row, on Oct. 2, 1968;

PF was the weight of the leaves remaining on the plants on Oct. 18, 1968;

B₆₈ was the weight of the prunings on Jan. 30, 1969, leaving a long wood of 8 buds on every plant (note that B was the last trait in a year even though it could actually be measured in the following year; note also that from this time on, the whole trial was managed in a uniform manner);

S was the carbohydrate content in the prunings, on a per plot sample from 3 of the 5 blocks; this content was somewhat low, probably because the prunings had been left to dry naturally, thus burning up part of their reserves;

in June 1969, the presence of clusters was scored on row 3 as G₆₉;

L was the total length of the shoots per plant, measured on June 25 and 30, 1969;

B₆₉ was the weight of the prunings measured during the winter 1969-1970, in g;

G₇₀ was the number of clusters per plot in Oct. 1970; their weight could not be determined due to damage from birds.

Table I shows the mean values of the traits measured.

2.3. Statistical analysis

The statistical analysis was performed using the progressive analysis of variance in multiple

Table I. Mean values of the traits measured.

	Mist				No mist			
	T	BB 0.5	BB 2.0	Man	T	BB 0.5	BB 2.0	Man
LAD*	100	69	48	46	100	35	20	9
N	11.0	6.5	5.4	5.3	11.0	4.7	3.7	2.6
PF	0	190	468	264	0	590	956	1222
S	1.9	5.0	6.2	6.5	3.6	5.9	12.7	12.6
B ₆₈	2 405	4 165	4 725	4 690	3 150	4 735	6 010	6 230
G ₆₉	0	4	5	6	1	15	28	32
L	1 742	2 651	2 699	2 790	2 032	2 737	3 018	3 205
B ₆₉	6 566	12 690	14 390	14 640	8 340	14 154	16 580	17 150
G ₇₀	22	38	36	39	30	38	41	35

LAD: leaf area destroyed: visual observation; N: average score for leaf destruction (1-11); PF and B are given in g, and L in cm.

regression according to Woolf [4]. With this technique, the regression of one dependent variable is calculated in a stepwise manner on several independent variables, adding one after the other. At each step, that part of the variance associated with the introduction of the last variable (LV) may be taken as the measure of the effect of this variable on the dependent variable, once the effect of the variables introduced earlier has been taken into account. Usually the optimal order is sought in which the next variable to be added is that which takes into account the maximum part of the remaining variance.

The originality of Woolf's method lies in the fact that by varying the order in which variables are introduced, it is possible to highlight the consequences of the correlation pattern between them, which could be difficult to detect by merely looking at the matrix, and which do not show up in the "optimal" order.

2.4. Sugar content of the canes

As the sugar content had only been determined on 3 replicates, we calculated 2 matrices for the coefficients of correlation: one based on the 24 plots thus defined, and one on the 40 plots making up the whole experiment. These are shown in Table II. These matrices are very close to one another, which is not surprising as there are 24 out

Table II. Matrices of correlations between traits.

	N	PF	B ₆₈	S	L	B ₆₉	G
N	1.00	-0.75	-0.64	-0.94	-0.89	-0.84	-0.46
PF	1.00	-0.70	-0.64	—	-0.89	-0.84	-0.55
		1.00	0.69	0.67	0.76	0.75	0.15
B ₆₈			1.00	0.60	0.70	0.83	0.46
				1.00	—	0.70	0.83
S				1.00	0.84	0.81	0.36
L					1.00	0.89	0.49
						1.00	0.89
B ₆₉						1.00	0.39
							1.00
							1.00

Critical values of $r_{22, .05}$: 0.404, $r_{22, .01}$: 0.515, $r_{38, .05}$: 0.325, $r_{01, 38}$: 0.500. Values for 38 d.f. have been approximated. Matrix 24: upper row; matrix 40: lower row.

of the 40 data in common; this also points to the good block to block homogeneity of the experiment.

3. Results

A number of analyses have been performed. We are presenting them in the following section, in as logical and biological an order as possible.

3.1. Regression of S on N and PF

This investigates the relative value of the 2 measured traits assumed to describe the importance of the damage done by mildew: scoring N on the one hand, and foliage left on the plants, PF, on the other. The analyses made from matrix 24 are shown in Table III.

The 2 possible orders of introduction yield quite different pictures. The sum of squares (SS) accounted for by the multiple regression on both variables is 0.883, which is very large. This is of course the same for both orders. But the 2 orders are quite distinct: while N, introduced first, accounts for almost all the variance accounted for by the regression (0.882 from 0.883), when PF is introduced first, it accounts for only 0.452, leaving 0.431 still to be accounted for by N. We can thus conclude that the visual score of the mildew damage provides a far better predictor of the sugar content in the canes at the end of the season than the weight of the leaves still left on the plants at the same period.

3.2. Conclusion

We thus reach the conclusion that most probably through the loss of actively photosynthesising foliage, the effect of mildew has mainly been that of reducing the amount of carbohydrates stored in the canes of the plants. This is very important, and demonstrates the value of studying young plants originated from cuttings: these had no previous history, i.e., no previously accumulated stored reserves from former seasons. This enabled us to assess the first year of a 3-year cycle, in a virtually pure state, in the absence of interaction with past events, which is impossible to achieve when experimenting on adult vines in which stored carbohydrates from former seasons compensate for the yearly variations.

The fact that N is a better predictor than PF can be explained by assuming that the leaves remaining on the plants which were weighed were to a large extent already dead, i.e., they had been non-photosynthesising for a long time.

Table III.

Order: S/N, PF

Reg	Res	D.f.			Mean squares			F	
		Reg	LV	Res	Reg	LV	Res	Reg	LV
0	23			1.000					
1	22	0.882	0.882	0.118	0.882	0.883	0.0053	164	164
2	21	0.883	0.001	0.117	0.442	0.001	0.0056	79.37	< 1

Order: S/PF, N

Reg	Res	D.f.			Sums of squares			Mean squares			F	
		Reg	LV	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
0	23			1.000								
1	22	0.452	0.452	0.548	0.452	0.452	0.0249	18.14	18.14			
2	21	0.883	0.431	0.117	0.442	0.431	0.0056	79.37	77.53			

Figures shown in the table result from the rounding up after computer calculation: hence there are minor discrepancies with the values recalculated from them. LV: last variable introduced, with 1 d.f.

3.2.1. The statistical technique

This first analysis also provides a good example of the technique of progressive regression with changes in order, as it shows how progress may differ in accounting for variance parts with changes in order, thus leading to meaningful conclusions on the biological plane [2].

3.3. Regression of L on B_{68} and N

This is shown in Table IV. The multiple regression is again highly significant. The order of introduction yields pictures that are different. As B_{68} has been affected by mildew (which accounts for 0.409 of its variation), it no longer provides further information for predicting L once N has been introduced.

3.4. Regression of L on N, S and PF

Table V shows the analyses for L on N, S and PF. Again, the multiple regression is highly significant,

and a change of order considerably alters that part of the variation accounted for by the last variable at each step.

Both N and S seem to be strong predictors of L: in fact, they are almost interchangeable, and once introduced first, leave little to be added by the other 2. This is not surprising, as the previous analyses have shown that they are very highly correlated, i.e., at 0.94.

3.5. Regression of B_{69} on L, B_{68} and N

Table VI shows the relationship of B_{69} to the traits in the preceding year, i.e., L, B_{68} and N. This presentation may look a bit clumsy. As each sub-multiple regression yields the same overall analysis of variance, they contain a number of redundancies. The most meaningful columns of the table have been shaded in, for that part of the sum of the squares or the mean square associated with the introduction of the last variable in each line. It can be observed that each of the independent variables

Table IV.

Order: L/ B_{68} , N

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
0	39			1.000					
1	38	0.485	0.485	0.515	0.485	0.485	0.0135	35.78	35.78
2	37	0.819	0.334	0.181	0.409	0.334	0.0049	83.58	68.15

Order: L/N, B_{68}

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
0	39			1.000					
1	38	0.791	0.791	0.209	0.791	0.791	0.0055	144.18	144.18
2	37	0.819	0.027	0.181	0.409	0.027	0.0049	83.58	5.59

Table V.

Order: L/N, S, PF

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
0	23			1.0000					
1	22	0.790	0.790	0.2094	0.790	0.7906	0.0095	83.09	83.09
2	21	0.791	0.0008	0.2086	0.396	0.0008	0.0099	39.84	< 1
3	20	0.814	0.0224	0.1862	0.272	0.0224	0.0093	29.14	2.40

Order: L/S, PF, N

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
0	23			1.000					
1	22	0.713	0.713	0.287	0.713	0.713	0.013	54.78	54.78
2	21	0.780	0.067	0.219	0.390	0.061	0.011	37.35	6.42
3	20	0.814	0.033	0.186	0.271	0.033	0.009	29.14	3.57

when first introduced accounts for a notable part of the overall variation, which reflects the fact that all are relatively highly correlated between themselves.

While B_{68} ranks last in this regard, it should be recalled that its correlation with N (0.65) was lower than that of L with N (0.89). When introduced last, B_{68} accounts for a part of the variation, which even though it is small, remains significant. We may interpret this by assuming that B_{68} carried over some influence of an initial component of vigour, intrinsic to the original plants before the experiment started, that it was unfortunately not possible to evaluate. If this is true, the variation thus accounted for represents the initial heterogeneity of the material. But this is only a hypothesis, which remains to be checked experimentally.

3.6. Regression of G on L, B_{68} , PF, N and B_{69}

Table VII shows the progressive analysis of the variance of the regression of G, the number of clusters borne by the plants in 1970, on the traits measured earlier.

As we have seen, G was unfortunately affected by damage due to birds. As a consequence, its residual variation was much larger than that for the other variables.

From the last table, we can conclude first that L, the total length of the shoots in June, seems the best predictor of fertility in the next year. This is in agreement with observations that locate floral initiation during the period from May to July, as well as those that associate floral initiation with the speed of growth of the shoots. In trellised vines that are pruned in summer, the length of the canes cannot play the same role, as they are all trimmed to approximately the same length, with the consequence that one has to rely on their weight, or diameter.

The variation in the cluster count made in 1969 also closely followed the variation of the indicators. One may observe that the mildew attack (the exact time of which was not reported) may have occurred later than the period of flower initiation in 1968, or at least only at the end of it. To explain the correlation, one might assume that in addition to a deficient flower initiation, the poor vigour of

Table VI.

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	LV
Order: B ₆₉ /L, B ₆₈ , N									
0	39			1.000					
1	38	0.784	0.784	0.216	0.784	0.784	0.0057	137.99	137.99
2	37	0.874	0.090	0.126	0.437	0.090	0.0034	128.17	26.34
3	36	0.883	0.009	0.117	0.294	0.009	0.0032	90.88	2.91
Order: B ₆₉ /L, N, B ₆₈									
0	39			1.000					
1	38	0.784	0.784	0.216	0.784	0.784	0.0057	137.99	137.99
2	37	0.797	0.013	0.203	0.399	0.013	0.0055	72.81	2.43
3	36	0.883	0.086	0.117	0.294	0.086	0.0032	90.88	26.52
Order: B ₆₉ /N, B ₆₈ , L									
0	39			1.000					
1	38	0.706	0.706	0.294	0.706	0.706	0.0077	91.40	91.40
2	37	0.853	0.161	0.147	0.426	0.161	0.0040	107.03	40.37
3	36	0.883	0.031	0.117	0.294	0.031	0.0032	90.88	9.43
Order: B ₆₉ /N, L, B ₆₈									
0	39			1.000					
1	38	0.706	0.706	0.294	0.706	0.706	0.0077	91.40	91.40
2	37	0.797	0.091	0.203	0.426	0.091	0.0055	107.03	16.63
3	36	0.883	0.086	0.117	0.294	0.086	0.0032	90.88	26.52
Order: B ₆₉ /B ₆₈ , L, N									
0	39								
1	38	0.692	0.692	0.692	0.692	0.692	0.0081	85.27	85.27
2	37	0.874	0.182	0.182	0.437	0.182	0.0034	128.17	26.34
3	36	0.883	0.009	0.009	0.294	0.009	0.0032	90.88	2.91
Order: B ₆₉ /B ₆₈ , N, L									
0	39			1.000					
1	38	0.692	0.692	0.308	0.692	0.692	0.0081	85.27	85.27
2	37	0.853	0.161	0.147	0.426	0.161	0.0040	107.03	40.394
3	36	0.883	0.031	0.117	0.294	0.031	0.0032	90.88	9.43

the damaged plants at bud burst in 1969, together with the heavy load that was applied to the plants (8 buds on small plants) resulted in post-bud-burst

losses in proportion to the mildew damage incurred. This is only a hypothesis, which should be further validated.

Table VII.Order: G/L, B₆₈, PF, N, B₆₉

D.f.		Sums of squares			Mean squares			Fs	
Reg	Res	Reg	LV	Res	Reg	LV	Res	Reg	DV
0	39			1.000					
1	38	0.333	0.333	0.667	0.333	0.333	0.0137	24.31	24.31
2	37	0.348	0.025	0.652	0.174	0.025	0.0176	9.89	1.42
3	36	0.383	0.035	0.617	0.128	0.035	0.0171	7.48	2.05
4	35	0.394	0.011	0.606	0.152	0.011	0.0173	8.77	< 1
5	34	0.412	0.018	0.588	0.082	0.018	0.0173	4.76	# 1

It is to be noted that Table XII, from Rives and Lafon (1972), contains a number of errors that have been corrected in the above Table VII.

4. Conclusion

This experiment did not involve the root system, however likely it is that the loss of photosynthesis must have had consequences on its development. The role of the roots in providing growth substances has been stressed, and they may also serve as a storage organ for carbohydrates. This also remains to be investigated in future experiments.

In my opinion, while the results on the system of relationships among the variables fit well with what was already known, the important feature of this experiment is to have shown that using small vine plants issued from cuttings, and inducing in them a variation in the different factors that may be connected with crop formation, one can isolate a single 3-year cycle. This eliminates the interaction between cycles that takes place in adult vines, in which the reserves accumulate over several years, and thus buffer the year-to-year variations.

The root system remains to be studied, as well as the relations between energy input and output and growth substances.

While the technique for inducing mildew attacks in an even progression can certainly be refined, it also remains to be seen whether mechanical removal of parts of the foliage at given times may not be a better technique.

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