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Statistical analysis of rootstock experiments as providing a definition of the terms vigour and affinity in grapes

by

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Over a big proportion of the world acreage under grapes, grafting on resistant rootstocks is a necessity or may be proved as beneficial. Phylloxera prevents the growing of *Vitis vinifera* cultivars on their own roots in most of the areas where it prevails, with the exception of the Cuyo district in Argentina, and perhaps some parts of Peru, where soil fertility, climate and irrigation, combined with good cultural practices seem to counteract the damages through sustained vigour.

Nematodes may be sufficiently damaging to make grafting necessary or at least advisable (Sauer 1967). A range of rootstock varieties of American parentage, though mainly bred in Europe some seventy to ninety years ago, provide a good spectrum of adaptation for most areas. However, nematode resistance does not seen to have reached its possible maximum.

In the vineyards of the old world resistance to lime chlorosis, the iron deficiency induced by bicarbonate in calcareous soils, is currently avoided through the use of hybrid rootstocks involving *Vitis Berlandieri* and sometimes *Vitis vinifera*. Though highly tolerant to lime, these species have so far transmitted to their progeny their inherent defects: poor rooting ability in *Vitis Berlandieri* and susceptibility to phylloxera damage in *Vitis vinifera*.

In addition, recent evolution in training in Western Europe has brought new problems into light. Economical factors have led to wider spacings and the growing of high vigour »free« forms. The leaf to fruit ratio is no longer checked through summer pruning and tends to increase beyond control. The consequences are a high incidence of post-bloom berry abortion or whole bunch abortion, an overall decrease in foliage efficiency due to mutual shading and to the blocking of photosynthesis from the premature closing of the stomata under the water stress caused by the very increase in leaf area, the build-up within the canopy of a micro-climate which is highly favorable to diseases especially grey mold (*Botrytis cinerea*) while the density of the canopy makes it harder for the sprays to reach their targets properly. This may be summarized by saying that these vines are »too vigorous«.

Vigour has always been a subject of concern for vine-growers in the old world where the balance between vigour and cropping is far more delicate than in new vineyard regions such as California or Australia, where reports such as those of Antcliff (1965) or Weaver, McCune and Amerine (1961) show that heavy loads or overcropping do not affect the vigour nor the yielding potential of the vines in the long run except with varieties such as Alicante Bouschet where virus infection may play a role.

Rootstock »vigour« has been recommended as a means to modulate overall vigour of the vine with the idea that low vigour is associated with earliness, quality and regularity of cropping, while high vigour leads to coulure or overcropping, delay in maturity and low quality. Balancing soil fertility and scion vigour with rootstock vigour has become a routine topic in advising growers. Breeding rootstock varieties of low vigour is one possible answer to the excessive vigour abtained in wide spaced, high trellis vineyards that answer the need of reducing cost in Western European vineyards.

Howewer while chlorosis resistance, wood yield, phylloxera tolerance and resistance to diseases are relatively easy to assess in early tests that minimize the costs of breeding in terms of space and labor, breeding for vigour would make it necessary to perform extensive trials with grafted vines. This is forbiddingly expensive in both time and space. This led us to investigate the feasibility of early tests of vigour.

Up to now however vigour appears as a purely intuitive concept. The heat of the controversy between the promoters of »vigour« and those of »affinity«, together with the lack of a properly objective definition of both concepts, is evidence of the need of clarifying this point before proceeding further. We shall first make it clear that there are two kinds of vigour as characteristics of a rootstock variety. The first one is the vigour of the plants of the variety itself as it is grown for the production of wood i. e. cuttings. The second one is the vigour exhibited by the vines obtained through the grafting of a *V. vinifera* scion onto this rootstock variety. I have proposed (Rives 1970 a) the use of term »own-vigour« (vigueur propre) for the first one and of »given vigour« (vigueur conférée) for the second one. It is a well known fact that there is no correlation between these two characteristics. What I am speaking of in the present paper and proposing to define and measure

Table 1
Pruning weights

	1	2	3	4	5	6	7	8	Sums
1	37	87	81	68	92	110	65	107	647
2	46	97	73	73	91	121	85	116	702
3	42	81	58	77	68	121	69	101	617
4	38	55	49	60	56	85	53	82	478
2	48	84	63	68	78	100	79	113	633
5	31	92	80	44	87	113	84	118	649
6	43	73	56	68	66	74	51	85	516
2	46	83	72	67	83	94	78	122	645
7	52	77	69	60	76	72	65	98	569
8	47	83	66	80	79	60	83	91	589
2	48	96	79	77	80	116	78	119	693
9	56	103	80	71	96	99	96	88	689
Sums	534	1011	813	952	1165	1165	886	1240	7427

Data from Snyder and Harmon (1948). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S.	F
Total	4346,4	95		
Scions	2846,7	7	406,7	37,657**
Rootstocks	671,4	11	61,0	5.648**
Error	828,3	77	10,8	
Non-additivity	101,7	1	101,7	10,6 **
Remainder	726,6	76	9,56	
Within-plots	5813,2	864	6,73	

is the second one, »given vigour«. A historical account of the controversy is given in my paper (Rives 1970 a).

In the mind of their champions, vigour and affinity may be seen as reflecting two opposite conceptions of the build up of vigour in a grafted vine. The first one maintains that resulting vigour is the sum of the vigour of the scion variety and of the given vigour of the stock, by an additive process. For the second one vigour results solely from an interaction between the properties of the stock and the scion. I have discussed these points at length in my paper (Rives 1970 a). My purpose is to present here a fuller account of a survey of published rootstock trials, whose analysis provides a good working definition of both concepts, and to show the generality of the phenomena that support these.

These trials are typical two-ways experiments, with tables which cells contain the data from all combinations between a range of rootstock varieties and of *V. vinifera* varieties. With one exception, there is no information on the error variance. Thus the only means to investigate interactions is the use of Tukey's test for non-additivity as outlined in Rives (1970 b). I have analysed all the experiments involving a sufficient number of levels in the two factors that I was able to find out. Most of them provide data which are the means of several vines for several years, for yield and for pruning wood weight.

Table 2

Fruit weights

	1	2	3	4	5	6	7	8	Sums
1	242	357	440	356	360	459	434	470	3118
2	257	357	410	376	311	522	520	432	3185
3	241	457	412	360	330	520	632	385	3337
4	233	369	401	369	310	483	634	552	3351
2	251	368	414	311	296	516	526	445	3127
5	223	392	414	297	330	434	348	293	2731
6	200	406	389	288	296	358	332	346	2615
2	250	440	477	354	316	531	516	478	3362
7	256	504	475	369	371	414	406	417	3212
8	249	429	421	332	344	422	482	422	3101
2	283	421	473	329	304	477	582	455	3324
9	225	399	311	224	262	356	406	353	2536
Sums	2910	4899	5037	3965	3830	5492	5818	5048	36999

Data from Snyder and Harmon (1948). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S.	F
Total	84074,9	95		
Scions	55063,6	7	7866,2	35,211**
Rootstocks	11811,6	11	1073,8	4,806**
Error	17199,7	77	223,4	
Non-additivity	2456,9	1	2456,9	12,67 **
Remainder	14742,8	76	193,9	
Within-plots	103131,0	864	119,0	

Tables 1 and 2 reproduce the data of Snyder and Harmon (1948), eliminating two varieties of *Vitis vinifera* for which the data are incomplete. These are nine years averages for fruit and wood weights and are given in tenths of pound per vines over plots of ten vines without replications in space.

1613 which was replicated appears four times. Varieties have been numbered as follows:

Rootstocks = lines

1 1202 (Mourvèdre × *V. rupestris)*
2 1613 (Solonis × Othello)
3 420 A MG *(V. Berlandieri* × *V. riparia)*
4 41 B (Chasselas × *V. Berlandieri)*
5 Constantia
6 *V. rupestris* var. St. Georges = du Lot
7 18815 *V. monticola* × *V. riparia)*
8 3309 C *(V. riparia* × *V. rupestris)*
9 Dog Ridge *(V. Champinii)*

Scions = columns

1 Muscat of Alexandria
2 Malaga
3 Flame Tokay (= Ahmeur bou Ahmeur)
4 Alphonse Lavallée (= Ribier)
5 Emperor
6 Sultanina (= Thompson Seedless)
7 Castiza (= Red Malaga)
8 Black Monukka

The analyses of variance, including Tukey's test for non-additivity are shown in the same tables.

Table 3
Logarithms of the within-plot sums of squares for fruit yield

	1	2	3	4	5	6	7	8	Sums
1	2504	2928	2671	3285	2981	2993	3245	3050	23657
2	2772	2993	2941	3309	2767	3285	3440	2894	24401
3	1949	3064	2840	3085	2418	3374	3456	3392	23578
4	2079	2831	2949	3060	2582	3172	3352	3411	23436
2	2403	3133	2704	3002	2710	3197	3575	3109	23833
5	3236	2582	2688	2932	2767	2576	3397	2346	22524
6	2243	2314	2782	2752	2594	2636	3098	3259	21678
2	2223	2782	2297	3320	2885	2607	3298	2563	21975
7	2338	2747	2114	3168	3004	2844	3149	3116	22480
8	2033	3433	2524	2704	2985	3092	3559	3082	23412
2	2558	2993	2907	3027	2859	2872	3394	3027	23637
9	2797	2920	1949	2425	2812	2589	3668	3008	22168
Sums	29135	34720	31366	36069	33364	35237	40631	36257	276779

Data from Snyder and Harmon (1948). Explanation see text.

Analysis of variance

	S.S.	D.F.	M S.	F
Total	14016698	95		
Scions	6962447	7	994635	12,683**
Rootstocks	1015622	11	92329	1,177 NS
Error	6038629	77	78424	

A special feature of these data was that probable error was given for each mean. From the formula for this statistic

$$P.E. = 0,6745\ s_{\bar{x}}$$

it is possible to compute the sum of squares for variations from the mean for each plot. Summing these sums of squares over the whole experiment yields the error or within-plots sum of squares, which can be compared with the residual sum of squares after deducing Tukey's sum of squares for non-additivity. This turns out to be slightly less than the residual. This is probably due to the fact that the residual includes variation due to field heterogeneity.

Non-additivity is highly significant for both measurements as well as the rootstock and scion varieties effects. In this case, the knowledge of within-plot variation makes it possible to make an analysis of variance of the within-plot variances after logarithmic transformation (Bartlett and Kendall 1946, as cited by Scheffé 1961, p. 84). This analysis (Table 3) shows that there are no significant differences between rootstocks but highly significant differences between scion varieties for intra-varietal heterogeneity in this trial.

Tables 4 and 5 give the data of Harmon (1949) for nine *V. vinifera* varieties and twelve rootstocks after elimination of one of both having incomplete data. The figures are averages of the twelfth and thirteenth years based on two replications of five vines for every combination except for the 1613 (number 9) where the

Table 4

Fruit yields

	1	2	3	4	5	6	7	8	9	Sums
1	101	216	118	93	177	160	242	153	168	1428
2	113	156	56	45	120	77	157	82	134	940
3	100	147	69	81	119	73	140	76	138	943
4	83	101	83	29	102	72	131	85	104	790
5	88	175	89	118	141	133	198	133	142	1217
6	125	138	79	86	124	62	159	82	112	967
7	106	174	51	51	133	121	174	119	119	1048
8	114	164	95	101	69	63	127	122	122	977
9	89	110	76	34	90	66	99	92	108	764
10	140	205	129	133	150	142	120	131	149	1299
11	114	135	150	166	127	73	139	140	147	1191
12	124	279	90	111	105	177	265	142	162	1455
Sums	1297	2000	1085	1048	1457	1219	1951	1357	1605	13019

Data from Harmon (1949). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S.	F
Total	207451	107		
Rootstocks	65246	11	5931	8,365**
Scions	79810	8	9976	14,071**
Error	62395	88	709	
Non-additivity	4569	1	4569	6,871*
Remainder	57826	87	665	

Table 5

Pruning wood weights

	1	2	3	4	5	6	7	8	9	Sums
1	30	45	25	21	60	21	38	60	106	406
2	29	19	17	07	24	09	22	20	46	193
3	18	20	17	19	23	16	18	21	45	197
4	24	15	23	22	50	07	12	20	37	210
5	11	43	30	43	57	27	35	61	58	365
6	18	18	18	12	27	09	20	18	43	183
7	24	31	14	14	44	16	26	41	38	248
8	21	31	18	15	39	09	15	38	35	221
9	18	14	14	05	18	07	09	19	31	135
10	32	48	29	25	49	18	19	39	64	323
11	32	35	21	56	84	10	25	36	56	355
12	33	69	29	63	93	37	63	48	97	532
Sums	290	388	255	302	568	186	302	421	656	3368

Data from HARMON (1949). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S.	F
Total	41990	107		
Rootstocks	16486	11	1499	13,265**
Scions	15541	8	1943	17,195**
Error	9963	88	113	
Non-additivity	2468	1	2468	28,698**
Remainder	7496	87	86	

averages are for ten replications of five vines. The data have been reconstructed from those of the standard of comparison (Rupestris St. Georges) and the differences from that as given by HARMON's Table 1. They are given in tenths of pound per vine.

Varieties are numbered as follows:

Rootstock (lines)

1 Dog Ridge
2 Salt Creek
3 41 B
4 420 A MG
5 1202
6 18815
7 101-14 (= *V. riparia* × *V. rupestris*)
8 3309 C
9 1613
10 Constantia
11 *V. monticola* × *V. rupestris*
12 *V. rupestris* du Lot

Scions (columns)

1 Sémillon
2 Sauvignon vert
3 Gewürztraminer
4 Chasselas doré
5 Silvaner
6 Petite Syrah
7 Carignan
8 Mondeuse
9 Cabernet Sauvignon

Table 6

Fruit yields

	1	2	3	Sums
1	2586	740	3074	6400
2	2047	1138	1983	5168
3	2002	702	1723	4427
4	1656	348	1139	3143
5	1625	567	1034	3226
6	1492	410	816	2718
7	1258	676	1405	3339
8	1199	453	1456	3108
9	1081	315	847	2243
10	1071	370	1382	2823
11	1031	413	1254	2698
12	937	544	1015	2496
13	913	294	1026	2233
14	761	286	1011	2058
15	694	975	1379	3048
16	540	198	359	1097
17	276	595	893	1764
Sums	21169	9024	21796	51989

Data from HARMON and SNYDER (1952). Explanation see text.

Analysis of variance

Total	S.S.	D.F.	M.S.	F
Total	18468926	50		
Rootstocks	6098395	2	3049197,5	26,567**
Scions	8697770	16	543610,6	4,736*
Error	3672761	32	114773,8	
Non-additivity	1533361	1	1533361	22,2184**
Remainder	2139400	31	69013	

The analyses of variance for fruit weight and wood weight are given in Tables 4 and 5 respectively. Here again non-additivity is highly significant.

Tables 6 and 7 reproduce the data of HARMON and SNYDER (1952). The experiment consisted of all the combinations between seventeen *V. vinifera* varieties and three rootstocks. The data are averages of the five last years of a fourteen years test, and are based on the ten vines in a single plot, without replication in space.

Varieties are numbered as follows:

Rootstocks (columns)

1 Solonis × Othello 1613 C
2 Rupestris St. Georges (= du Lot)
3 Dog Ridge

Scions (lines)

1 Carignan
2 Alexandria × Alicante Bouschet
3 Feher Szagos
4 Sauvignon vert
5 Mantuo di Pilo
6 Silvaner
7 Cinsaut
8 Petite Syrah
9 Palomino
10 Chabach
11 Semillon
12 Mission
13 Serektia
14 Zinfandel
15 Refosco
16 Muscat de Frontignan
17 Alicante Bouschet

Table 7

Pruning wood yields

	1	2	3	Sums
1	234	76	495	805
2	137	62	199	398
3	294	78	515	887
4	235	41	234	519
5	290	162	353	805
6	239	32	342	613
7	116	126	298	540
8	82	43	182	307
9	208	72	314	594
10	252	46	406	704
11	149	79	318	546
12	194	132	289	615
13	270	115	247	632
14	61	27	147	235
15	114	179	357	650
16	195	41	109	345
17	34	81	202	326
Sums	3113	1392	5016	9521

Data from Harmon and Snyder (1952). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S.	F
Total	726053	50		
Rootstocks	386601	2	193300,5	41,125**
Scions	189042	16	11815,1	2,514*
Error	150410	32	4700,3	
Non-additivity	57032	1	57032,0	18,933**
Remainder	93378	31	3012,2	

The analyses of variance for fruit weight (Table 6) and wood weight (Table 7) again show that non-additivity is significant.

Table 8 gives the data of Constantinescu (1963). The figures are ten years average yields of fruit in hectokilos per hectare for single plots without replications for all the combinations between twenty-three *V. vinifera* varieties and nine rootstocks. There is no indication about the total number of vines per plot in the original paper; proportions of surviving vines are given, but author does not explain how the averages were computed.

The varieties are numbered as follows:

Rootstocks (columns)

1 Riparia-Gloire
2 3306 C
3 3309 C
4 ARG nº 1 *(V. vinifera × V. rupestris)*
5 Rupestris du Lot
6 1202
7 420 A MG
8 8 B *(V. Berlandieri × V. riparia)*
9 41 B

Scions (lines)

1 Tamiioasa romineasca
2 Grasa de Cotnari
3 Feteasca alba
4 Mustoasa
5 Galbena de Odobesti
6 Basicata
7 Crimposie
8 Gordin
9 Braghina
10 Babeasca neagra
11 Negru moale
12 Negru virtos
13 Muscat Ottonel
14 Furmint
15 Pinot gris
16 Sémillon
17 Sélection Carrière
18 Aligoté
19 Sauvignon
20 Rhein Riesling
21 Pinot noir
22 St. Emilion
23 Cabernet Sauvignon

Once again the analysis of variance (Table 8) shows that non-additivity is significant.

Thus the analysis of several rootstock trials reveals a constant feature of the overall variation in such experiments : the differences between rootstocks or beween scions are significant, and at the same time the interaction between these two factors is also significant. Variation among varieties of rootstocks is generally smaller than among varieties of *V. vinifera* scions. This is the same conclusion as that of FREITAS and DA SILVA PATO (1968). To my knowledge, their experiment is the only published rootstock experiment to have been laid out in the form of a complete factorial design, including rootstocks, scions and locations as factors. Here again, all the main effects and their interactions are significant. Leaving alone for the moment the influences of environment, we can arrive from these analyses to a statistical definition of vigour (given) and affinity that is objective.

Considering the plant resulting from grafting a given scion variety on a given rootstock, its vigour, measured for example by the pruning wood weight, is shown to result from the summation of three effects: one is an additive property of the scion, the second one is an additive property of the rootstock and the third one is a property of the specific pair whose combination is measured. The additive effects of the rootstock variety we shall name »given vigour«, and the non-additive part specific of the given pair we shall name »affinity«. Expanding our definitions over the whole range of the sets of all possible scions and of all possible rootstocks, we shall say that given vigour is the additive component contributed by the rootstoks to the overall variation of all possible combinations between rootstocks and scions and that affinity is the non-additive component of this variation due to the specific interaction between stocks and scions. The formal analogy of these definitions with the genetic concepts of general and specific combining ability is obvious.

Considering the interaction of both scion and stock with environment (FREITAS and DA SILVO PATO 1965) and using the statistical random effects model of EISENHARDT (1947; see SNEDECOR 1959, p. 257 sqq, and RIVES 1970 c) these above mentioned definitions may be useful in allowing the measurement of the effects and their even-

Table 8
Fruit yields

	1	2	3	4	5	6	7	8	9	Sums
1	77	91	94	97	69	85	112	108	107	840
2	90	95	95	91	72	77	113	106	98	837
3	88	89	86	88	81	84	99	106	110	831
4	108	107	122	114	91	93	118	95	129	977
5	114	151	163	123	115	155	132	160	153	1266
6	114	109	116	104	98	100	126	125	121	1013
7	52	86	81	88	69	92	98	73	70	709
8	137	134	156	123	161	160	200	168	165	1404
9	102	102	90	92	98	98	97	111	99	889
10	103	102	129	105	80	111	138	132	139	1039
11	102	105	109	147	100	105	125	141	111	1045
12	81	98	88	101	96	102	123	84	105	878
13	100	98	107	85	80	84	104	92	77	827
14	90	79	92	78	72	91	89	103	112	806
15	77	80	84	71	83	75	93	89	104	756
16	96	107	110	92	72	79	111	123	125	915
17	123	114	111	104	114	119	144	149	153	1131
18	118	126	133	112	115	113	133	149	146	1145
19	90	110	127	95	95	89	125	114	133	978
20	77	79	89	65	62	75	87	94	99	727
21	87	73	113	94	92	82	79	112	104	826
22	82	107	125	103	136	114	112	137	117	1033
23	75	75	96	66	74	84	98	95	99	762
Sums	2183	2317	2516	2228	2125	2267	2656	2666	2676	21634

Data from CONSTANTINESCU (1963). Explanation see text.

Analysis of variance

	S.S.	D.F.	M.S	F
Total	117237	206		
Scions	76137	22	3460,7	25,806**
Rootstocks	17507	8	2188,4	16,319**
Error	23593	176	134,1	
Non-additivity	675,6	1	675,6	5,157*
Remainder	22917,4	175	131,0	

tual correlation with specific properties of the rootstock clones. Insofar as such correlations are indeed experimentally established with properties of the rootstocks that are measurable on young seedlings they should provide much welcome early tests for selecting rootstock varieties with a specified given vigour.

It is important to note that a clear distinction has to be kept between non-additive associating ability (i. e. affinity) and graft-compatibility (or incompatibility) whose origin is different.

The effect of virus infection was not taken into account as no information was available on this point. It will have to be excluded or controlled as far as possible in future work in this field.

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