DISTRIBUTION OF PHOTOSYNTHATES TOWARDS THE GRAPES: EFFECTS OF LEAF REMOVAL AND CLUSTER THINNING APPLIED BEFORE VERAISON IN cv. VERDEJO

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Abstract

Context and purpose of the study – The relationship between grape production and leaf surface is a highly debated aspect in terms of the impact it may have on the composition and quality of grapes, especially in areas that focus their cultivation on high-quality wine. In many occasions, the limitation of the unitary production level in these areas is claimed to be the main factor for achieving high quality levels in the wine, forgetting the importance of the source-sink relationship and other environmental factors and management of the canopy. Taking this consideration into account, this work seeks to know the response of the vine as a whole, and the individual shoot as well, to the application of various alternatives of leaves and clusters removal, carried out in the phase immediately before veraison, in cv. Verdejo, in Spain.

Material and methods – Throughout the 2017-2019 period, the productive and qualitative response of cv. Verdejo, grafted on 110-R, was studied through the application, in the pre-veraison phase, of the following experimental treatments: T, control treatment (normal shoots); DT, total defoliation (total leaf removal of a shoot of each spur, fully respecting the other shoot); A, cluster abscense (total defoliation of a shoot of each spur and complete cluster elimination of the other shoot); DP, partial defoliation (leaves removed from the cluster node on one shoot of each spur, fully respecting the other shoot). The design of the experiment is based on 4 random blocks, with an elementary plot of 6 vines to be measured, in a vineyard conducted on a vertical trellis, planted in 2012 with vine distances of 2.8 x 1.4 m, and pruned as a bilateral Royat cordon with 8 spurs (2-bud) per vine.

Results – The application of treatment A caused a noticeable reduction of productivity and Ravaz index, without hardly affecting the vegetative growth, despite removing the leaves from one of the two shoots of each spur, probably favored by the reduction in half of the sinks (clusters). On the contrary, the treatment DT caused light reduction of vegetative growth, as well as sugar concentration, as a consequence of reduction of half of photosynthates source (leaves). The treatment DP did not have noticeable effects on productive or vegetative behaviour. Treatments T (control) and A favored an increase in pH, a reduction in acidity and a slight increase in potassium, compared to DT and DP, probably due to the higher overall leaf-cluster ratio in the former. Regarding the type of shoot within each treatment, the HT type hardly reduced grape production compared to N type, within the DT treatment, but showed a decrease in both vigor and sugar concentration, related to the reduction in the ratio source-sink. The HP shoot type did not show notable differences with respect to N, within the DP treatment. The comparison between HT-type shoots showed a significant increase in sugars and a slight reduction in total acidity in that of treatment A versus that of DT, probably derived from the non-existence of sinks in the other shoot (RT) of treatment A. In summary, the complete removal of leaves on one of the two shoots of each spur, without reducing the crop load, produced a limitation of photosynthates that affected the quantitative and qualitative response of the plant, while the removal of leaves from the node of the cluster or the alternate combination of cluster thinning and leaves removal did not cause significant alteration or redistribution of photosynthates in the vine.

Keywords: acidity, sugars, Ravaz index, ripening, vigor.

1. Introduction

The relationship between grape production and leaf surface is a highly debated aspect in terms of the impact it may have on the composition and quality of the grape, especially in producing areas that focus their cultivation on high-quality wine, up to the point that it has come to propose the generalization of ratio levels between leaf area and harvest load (Kliewer and Dokoozlian 2005). On many occasions, the limitation of the unit production level is claimed as the main factor to achieve high quality levels in the wine, forgetting the importance of the source-sink relationship and other environmental and canopy management factors (Keller 2015). Organic compounds, produced during photosynthesis and nutrient assimilation, must be transported from the leaves to other sinks, with special relevance to the clusters. The distribution occurs as a function of the global resources of the plant, at various scales, since the accumulation of substances in the berry depends on the dimension of foliar structure, the productive efficiency of assimilates from leaves and the competition between organs of reserve and growth (Wisdom and Considine 2022).

Canopy management operations, including defoliation and cluster thinning, can be used to improve the source-sink relationship for grapes, through the modification of the internal metabolism of the plant (Candar et al. 2020). The mechanisms involved in the distribution of assimilates in the different sink organs are diverse and complex (Taiz and Zeiger 2006). Thus, said distribution depends on the proximity of the organs, according to which, although the leaves of a shoot export assimilates to other shoots, the closer the source is, the more likely the arrival of assimilates to the sink. For this reason, a cluster would receive photoassimilates mostly from the closest or adjacent leaves. However, defoliation of one shoot triggers the import of assimilates into clusters from other nearby shoots, while thinning of clusters from one shoot may induce export of assimilates to nearby shoots with clusters. On the other hand, the competition between sinks determines the priority of attracting assimilates. In this sense, the clusters have great priority from the setting, especially from adjacent and nearby leaves, but after veraison they must compete with the reserve organs (Candolfi-Vasconcelos et al. 1994), which conditions the final accumulation of assimilated in grapes.

The functional relationship between vegetative and reproductive organs must be considered in the context of the influence of various factors, including climate, soil, plant material -mainly the grape variety- and vineyard management, for which reason the pattern of distribution and storage of assimilates cannot be extrapolated to all situations and must be approached with the support of experimentation in each viticultural domaine. Taking into account the previous considerations, the work seeks to know the response of the vine as a whole, as well as of the individual shoots, to the application of various alternatives for the removal of leaves and clusters, carried out in the phase immediately prior to the veraison, in cv. Verdejo, to assess its possible suitability in vineyard management in the semi-arid growing conditions of the Duero river valley (Spain).

2. Material and methods

Vegetal material and localization - The trial was carried out throughout the period 2017-2019 in Valladolid (Castilla y Leon, Spain). The vines, planted in 2012, are from cv. Verdejo, grafted on 110R. The vine distances are 2.8 m x 1.4 m (2,551 vines/ha). The vines are trellised, with a bilateral Royat cordon and vertical positioning of the vegetation. The row orientation is NNE (N+25º). The pruning load was 16 buds per vine, in 8 spurs of 2 buds. A green pruning operation was applied every year after the spring frost risk period, to adjust the shoot load per vine. The cultivation of the vineyard was carried out through the support of deficit irrigation (25% ETo) from the pea-size stage until the week before the harvest.

Experimental treatments - The experimental treatments (figure 1) consist of the application, in the pre-veraison phase, of green operations: **T**, control (full shoots: type N); DT, total defoliation (total leaf removal of a shoot of each spur -HT-, fully respecting the other spur shoot -N-); A, cluster thinning (total leaf removal of a shoot of each spur -HT- and complete cluster elimiation of the other shoot of the spur -RT-); DP, partial defoliation (leaf removed from the cluster node on a shoot of each spur -HP-, fully respecting the other shoot of the spur -N-). The experimental design of the trial is in 4 random blocks, with an elemental plot of 6 control vines. The average temperature and rainfall data for the period 2017-2019 are detailed in table 1.

Statistical analysis - Statistical analysis was carried out using simple ANOVA of the treatments, separating the means using Duncan's test (p<5%).

Table 1: Values of temperature and rainfall of campaigns 2017, 2018 and 2019, in Valladolid. Tm, mean temperature (ºC): **Tm_a**, **Tm_c**, **Tm_v**; Tmax, mean of maximum temperature (ºC): **$Tmax_a$**, **$Tmax_c$**, **$Tmax_v$**; Tmin, mean of minimum temperature (ºC): **$Tmin_a$**, **$Tmin_c$**, **$Tmin_v$**; P, rainfall (mm): **P_a**, **P_c**, **P_v**. The periods correspond, according to subscripts, to dates: **a** (annual): 1-oct/30-sep; **c** (cycle): 1-abr/30-sep; **v** (summer): 1-jul/30-sep.

Campaign g	**Tm_a**	**Tm_c**	**Tm_v**	**$Tmax_a$**	**$Tmax_c$**	**$Tmax_v$**	**$Tmin_a$**	**$Tmin_c$**	**$Tmin_v$**		**P_a**	**P_c**	**P_v**
2017	13.1	18.9	20.6	20.7	27.5	29.3	6.2	10.5	12.0		262.1	98.2	47.0
2018	12.4	18.0	21.6	19.5	25.9	30.9	6.1	10.8	13.1		521.8	270.2	50.2
2019	12.4	17.6	20.8	19.9	25.7	29.2	5.7	9.8	13.0		302.5	137.4	75.2

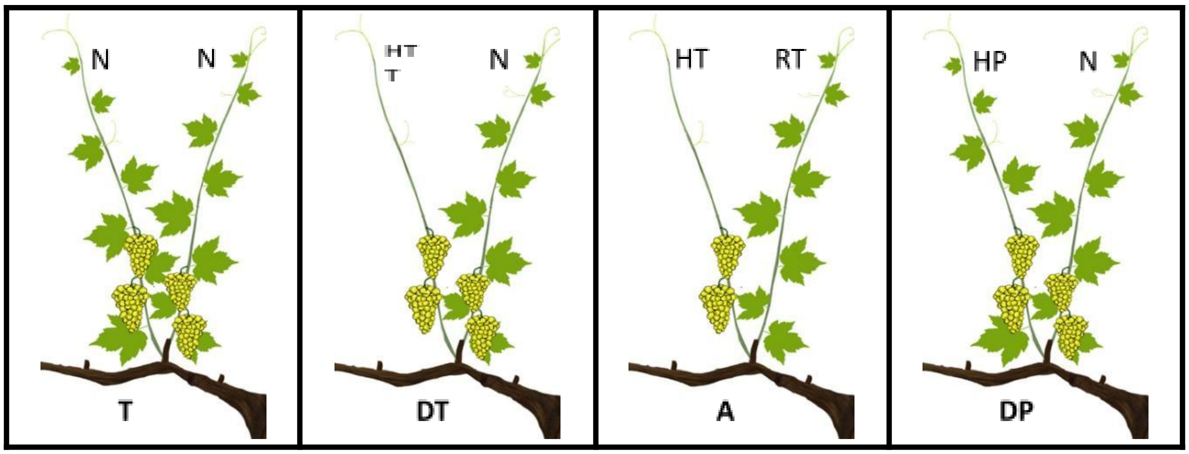

Figure 1: Scheme of treatments (T, DT, A, DP) applied to the spurs, in each vine, through the types of shoot in each treatment (T: N-N, DT: N-HT, A: RT-HT, DP: N-HP).

3. Results and discussion

3.1. *Production and yield components*

Grape production (table 2) was significantly reduced in treatment A every year, due to the elimination of clusters from half of the shoots by thinning. The average decrease was 49% with respect to the other three treatments, among which there were hardly any differences, with values around 3.33 kg/vine. Said reduction was exclusively due to the number of clusters, which decreased in treatment A by 46% on an interannual average with respect to the set of other treatments. The cluster weight showed a slightly lower value, 7.4 g less, in treatment A than in the other treatments, due to a slightly lower number of berries, 77.7 versus 85.8, without significant differences. Berry weight did not show statistically significant differences either, although its mean value was slightly higher in treatment A, 1.60 g, and lower in DP, 1.49 g, than in the other two treatments.

Regarding the type of shoot (table 5), within each experimental treatment, no notable differences were observed between the normal shoot (N) and the intervened shoot (HT or HP) in grape production, neither within the DT treatment nor less within the PD treatment. None of the yield components was noticeably affected depending on the type of shoot, only observing, within the DT treatment, a slight tendency to reduce the average number of clusters and berry weight in the HT type, which slightly affected grape production, while within the DP treatment a slight tendency to decrease the cluster weight was observed in the HP type that did not modify the grape production. In the comparison between HT-type shoots, that of treatment A showed a slight tendency to increase the number of clusters, but a lower cluster weight, despite increasing the berry weight, which only caused a slight favorable difference in the grape production compared to the HT type of the DT treatment.

3.2. V*egetative growth and Ravaz index*

The weight of pruning wood (table 3) was not significantly affected by the treatments applied, but the DT treatment and, more slightly, A treatment, both with total leaf removal of a shoot from each spur, reduced the weight, especially with respect to to the control (T), which showed the highest average value, 1.15 kg/vine. The

shoot weight showed a trend closely related to the weight of pruning wood, with the treatments DT and A being the ones with the lowest average value, 70.15 g, while the number of shoots per vine barely varied interannually, with values between 15.3, in DP, and 15.8 in T, due to the load adjustment, for approximation to 16 shoots per vine, carried out every year in spring. The Ravaz index decreased significantly in treatment A, to a mean value below 2, compared to the rest of the treatments, which overall exceeded a value of 3, with the control treatment (T) being slightly below DP and DT.
Regarding the type of shoot (table 5), within the DT treatment, the HT shoot was significantly less vigorous than the N; within treatment A, the HT shoot was somewhat more vigorous than the RT; and within the DP, there was hardly any favorable difference of the HP shoot with respect to the N. In the comparison between HT-type shoots, that of treatment A showed a clear increase in vigor compared to that of treatment DT. In all cases the differences were due to the trend of the shoot weight. The Ravaz index showed hardly any differences between the shoot types, except for the significant increase in the HT shoot of the DT treatment, both against the N of the treatment itself, and against the HT of the A treatment.

3.3. *Maturity and grape composition*

The sugar concentration (table 4) was significantly reduced in the DT treatment with respect to the other treatments, due to the significant differences found in the second and third years of the study, reaching an average value of 23.1 ºbrix, almost 1ºbrix lower than the control treatment (T), which averaged 24.0 ºbrix.
The pH of the must was significantly higher, in the first two years, in the T and A treatments, averaging around a value of 3.62, than in the DT and DP treatments, which averaged around a value of 3,51. The total acidity corresponded inversely with the observed pH level, although the differences were not statistically significant, resulting in the grapes from treatments T and A with lower acidity than those from DT and DP.
Tartaric acid did not show notable differences between treatments, with values that averaged between 7.91, in DP and T, and 8.12 g/L, in DT. Malic acid did not show statistically significant differences either, but treatment A presented the highest mean value, at 1.83 g/L, while treatments DT and DP presented the lowest mean values, around 1.64 g/L.
The concentration of potassium at harvest showed a close relationship with the pH of the grape in the different treatments applied, the value being higher in treatments A and T, 1721 and 1792 mg/L, and lower in DP and DT, 1666 and 1685 mg/L, although the differences were not statistically significant.
Regarding the type of shoot (table 5), within the DT treatment, the HT shoot significantly reduced the sugar level and slightly increased both the total acidity and the tartaric and malic acidity; within the DP treatment, hardly any differences were observed between the two types of shoot; in the comparison between HT-type shoots, that of treatment A showed a significant increase in sugars, of almost 1 ºbrix, and an average reduction of total acidity of 0.25 g/L, compared to that of treatment DT.

4. Conclusions

Grape production was significantly reduced every year due to cluster thinning (A), an average of 49%. On the contrary, the DT and DP treatments did not show hardly any differences with respect to the control (T). The grape yield reduction in treatment A was due to the decrease in the number of clusters, a 46% interannual average, since the rest of the yield components were barely affected, since the cluster weight of A barely showed a value slightly lower, despite the fact that the berry weight was slightly higher, than the other treatments. Regarding the type of shoot, within each treatment, no noticeable differences were observed between the normal shoot (N) and the intervened shoot (HT or HP) in grape production, although within the DT treatment the HT shoot showed a slight reduction in number of clusters and berry weight, which slightly affected grape production.
The weight of pruning wood was not significantly affected by the treatments applied, but the treatments DT and, more slightly, A, both with total defoliation of a shoot per spur, reduced said weight, especially with respect to the control (T), which showed the highest average value, closely related to the trend of the shoot weight. The Ravaz index decreased significantly in treatment A compared to the rest of the treatments, with the control (T) being slightly below DP and DT. Regarding the type of shoot, the HT shoot was less vigorous than the N within the DT treatment, but somewhat more vigorous than the RT shoot within the A treatment, with hardly any differences between the HP and N shoots within the DP treatment, finding always closely related to the weight of the shoot.

The sugar concentration was significantly reduced in the DT treatment with respect to the other treatments, almost 1 ºBrix lower than the control (T). The must pH was significantly higher in treatments T and A than in DT and DP. Total acidity corresponded inversely with the pH trend, resulting in grapes from treatments T and A with lower acidity than those from DT and DP. Tartaric acid and malic acid did not show significant differences. The potassium concentration showed a close relationship with the pH of the grape, being slightly higher in treatments T and A than in DT and DP. Regarding the type of shoot, the HT type significantly reduced the sugar level and slightly increased the acidity of the grape within the DT treatment, while the HP type did not show differences compared to N within the DP treatment. The comparison between HT-type shoots showed a significant increase in sugars and a slight reduction in total acidity in that of treatment A versus that of DT, probably derived from the non-existence of sinks in the other shoot (RT) of treatment A.

5. Acknowledgements

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6. Literature cited

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Table 2: production (kg/vine), number of clusters per vine, cluster weight (g), number of berries per cluster, berry weight (g) and Ravaz index, in the period 2017-2019, of T, DT, A and DP treatments. Significance levels: not significant (-); p<0.05 (*). Different letters indicate significant differences between treatments.

Treat.	2017	2018	2019		2017	2018	2019		2017	2018	2019	
	Production			Ave.	Clusters / vine			Ave.	Cluster weight			Ave.
T	2.70 *a*	3.30 *a*	4.01 *a*	3.34	22.8 *a*	26.9 *a*	26.9 *a*	25.5	118.3	122.9	148.6	129.9
DT	2.66 *a*	3.47 *a*	4.00 *a*	3.38	21.9 *a*	29.4 *a*	28.3 *a*	26.5	122.3	118.4	141.6	127.4
A	1.38 *b*	1.69 *b*	2.03 *b*	1.70	12.0 *b*	15.0 *b*	15.3 *b*	14.1	116.3	112.7	133.2	120.7
DP	2.69 *a*	3.19 *a*	3.93 *a*	3.27	21.8 *a*	28.3 *a*	26.8 *a*	25.6	122.6	112.9	145.6	127.0
Sig.	*	*	*		*	*	*		-	-	-	
	Berries / cluster			Ave.	Berry weight			Ave.	Ravaz index			Ave.
T	85.6	59.0	104.7	83.1	1.37	1.95	1.43	1.58	2.86 *a*	2.37 *a*	3.61 *a*	2.95
DT	91.1	62.9	108.1	87.4	1.35	1.91	1.37	1.54	3.02 *a*	2.66 *a*	3.88 *a*	3.19
A	83.4	59.2	90.5	77.7	1.39	1.93	1.47	1.60	1.62 *b*	1.29 *b*	1.93 *b*	1.62
DP	90.1	81.0	89.6	86.9	1.35	1.62	1.50	1.49	3.09 *a*	2.29 *a*	3.71 *a*	3.03
Sig.	-	-	-		-	-	-		*	*	*	

Table 3: pruning wood weight (kg/vine), number of shoots per vine and shoot weight (g), in the period 2017-2019, of T, DT, A and DP treatments. Significance levels: not significant (-); p-value<0.05 (*). Different letters indicate significant differences between treatments.

Treat.	2017	2018	2019		2017	2018	2019		2017	2018	2019	
	Pruning wood weight			Ave.	Number of shoots			Ave.	Shoot weight			Ave.
T	0.914	1.396	1.129	1.146	15.9	15.6	16.0	15.8	58.4	89.8	70.6	72.9
DT	0.881	1.310	1.037	1.076	15.2	15.2	15.8	15.4	58.3	86.5	65.6	70.2
A	0.890	1.324	1.066	1.093	15.5	15.5	16.0	15.7	57.7	86.0	66.7	70.1
DP	0.896	1.383	1.094	1.124	15.1	15.4	15.3	15.3	60.0	89.9	72.4	74.1
Sig.	-	-	-		-	-	-		-	-	-	

Table 4: Total soluble solids (ºBrix), pH, titratable acidity (g TH_2/L), tartaric acid (g/L), malic acid (g/L) and potassium (ppm), in the period 2017-2019, of T, DT A and DP treatments. Significance levels: not significant (-); p<0.05 (*). Different letters indicate significant differences between treatments.

Treat.	2017	2018	2019		2017	2018	2019		2017	2018	2019	
	Total soluble solids			Ave.	pH			Ave.	Total acidity			Ave.
T	24.4	24.4 *a*	23.3 *a*	24.0	3.71 *a*	3.84 *a*	3.34	3.63	4.66	5.07	6.11	5.28
DT	24.3	23.8 *b*	21.1 *b*	23.1	3.55 *c*	3.75 *b*	3.22	3.51	4.77	5.18	6.51	5.49
A	24.2	24.1 *ab*	22.5 *a*	23.6	3.69 *ab*	3.86 *a*	3.29	3.61	4.73	5.13	6.20	5.35
DP	24.3	24.2 *a*	22.9 *a*	23.8	3.56 *bc*	3.70 *b*	3.28	3.52	4.81	5.29	6.47	5.53
Sig.	-	*	*		*	*	-		-	-	-	
Treat.	Tartaric acid			Ave.	Malic acid			Ave.	Potassium			Ave.
T	8.71	7.65	7.41	7.92	1.35	2,02	2.01	1.79	1990	1865	1520	1792
DT	8.91	7.69	7.75	8.12	1.22	1,91	1.80	1.64	1873	1778	1403	1685
A	8.65	7.78	7.60	8.01	1.55	1,99	1.94	1.83	1970	1773	1420	1721
DP	8.74	7.58	7.42	7.91	1.18	1,91	1.86	1.65	1850	1701	1447	1666
Sig.	-	-	-		-	-	-		-	-	-	

Table 5: Average value (2017-2019) of: production (kg/vine), number of clusters per vine, cluster weight (g), number of berries per cluster and berry weight (g); pruning wood weight (kg/vine), number of shoots per vine, shoot weight (g) and Ravaz index; total soluble solids (TSS, ºBrix), pH, total acidity (g TH_2/L), tartaric acid (g/L), malic acid (g/L) and potassium (K, ppm); of each type of shoot (N, HT; RT, HT; N, HP) within the DT, A and DP treatments.

Treat.-Shoot		Prod.	N. clust.	Cluster wt.	N. berr.	Berry wt.	Prun. wt.	N. shoots	Shoot wt.	Ravaz Ind.	SST	pH	A. total	A. tart.	A. malic	K
DT	**N**	1.71	13.4	127.4	85.2	1.57	0.621	7.9	79.9	2.84	23.5	3.55	5.41	8.03	1.57	1653
	HT	1.67	13.1	127.8	86.0	1.54	0.455	7.6	60.3	3.73	22.7	3.50	5.60	8.21	1.72	1713
A	**RT**						0.500	7.9	64.0							
	HT	1.70	14.1	120.7	77.7	1.60	0.593	7.8	76.0	3.08	23.6	3.61	5.35	8.01	1.83	1721
DP	**N**	1.64	12.6	128.4	81.1	1.61	0.554	7.8	72.5	3.08	23.9	3.52	5.51	7.87	1.71	1695
	HP	1.65	13.1	126.4	79.0	1.59	0.570	7.5	75.9	3.05	23.8	3.51	5.57	8.00	1.60	1629