NITROGEN DILUTION IN EXCESSIVE CANOPIES OF CHASSELAS AND PINOT NOIR CVS

Jean-Laurent SPRING, Thibaut VERDENAL,
Vivian ZUFFEREY and Olivier VIRET

Station de recherche Agroscope Changins-Wädenswil ACW, CP 1012,
1260 Nyon 1, Switzerland

Abstract

Aims: The impact of canopy management on the nitrogen (N) content in grapevines was studied.

Methods and Results: Two trials were carried out between 2001 and 2010 on *Vitis vinifera* cvs. Chasselas and Pinot noir. The observed factors of variation were the intensity of lateral shoot removal for the first trial and the severity of shoot trimming for the second trial. The N content was evaluated in parallel by leaf diagnosis, the chlorophyll index and the yeast available N concentration (YAN) found in the musts. When the yields were the same, a significant dilution of N in proportion to the development of the leaf area was revealed. Treatments resulting in excessive leaf area presented N deficiency in the leaves and the musts.

Conclusion: The N content in both the vines and grapes was influenced by the canopy management (lateral shoot removal and shoot trimming), and the magnitude of the response appeared to be even greater in the absence of water stress. In addition, the risk of N deficiency was found to increase beyond a maximum value of the leaf-fruit ratio.

Significance of the study: Canopy management has a significant influence on the N content in foliage and grapes, and the risk of N deficiency increases under a situation that produces an excessive leaf area.

Key words: nitrogen deficiency, leaf-fruit ratio, canopy management, grapevine

Résumé

But : Deux essais ont été suivis entre 2001 et 2010 sur Chasselas et Pinot noir (*Vitis vinifera*) dans le but d'étudier l'impact de la gestion du feuillage sur la teneur en azote (N) dans la vigne.

Méthode et résultats : Les facteurs de variations étaient la quantité d'entre-cœurs supprimés dans le premier essai, et la hauteur du rognage dans le deuxième essai. La teneur en N a été contrôlée par le diagnostic foliaire, par l'index chlorophyllien, ainsi que par l'analyse de la teneur des moûts en azote assimilable. Un effet significatif de dilution de N proportionnel au développement de la surface foliaire a pu être constaté. À rendements égaux, les variantes ayant les plus grandes surfaces foliaires ont présenté les teneurs en N les plus faibles dans le feuillage et dans les moûts.

Conclusion : La teneur en N de la vigne et des raisins est significativement influencée par la gestion de la surface foliaire (suppression des entre-cœurs et rognage), et le niveau de réponse est plus important pendant les années plus humides. Dans le cas d'une surface foliaire excessive, les risques de carence azotée augmentent.

Importance de l'étude : La gestion du feuillage de la vigne influe significativement sur le taux de N dans la vigne et les raisins, et semble être une méthode intéressante pour réduire la carence azotée dans les vignes vigoureuses et dans le raisin.

Mots-clés : carence azotée, rapport feuille-fruit, surface foliaire, vigne

manuscript received 12rd March 2010 - revised manuscript received 18th July 2011

J. Int. Sci. Vigne Vin, 2012, **46**, n°3, 233-240

*Corresponding author: jean-laurent.spring@acw.admin.ch

INTRODUCTION

In quantitative terms, nitrogen (N) is the 4th most abundant element and the most abundant mineral element in plants, representing 1 to 4 % of the dried matter (Hopkins, 2003). Nitrogen is a component of major molecules, including proteins, DNA and chlorophyll (Crespy, 2007). Under non-limiting water conditions, nitrogen is the quintessential factor determining vigour ; a high nitrogen supply greatly influences the leaf-fruit ratio by favouring vegetative growth, including the growth of lateral shoots, which can result in dense canopies associated with less soluble solids, higher acidity and poor colour of the fruit (Keller, 2010). In contrast, wines produced from N-deficient grapevines tend to be more astringent, with fewer aromas, and are usually penalized during wine tastings, particularly with regard to white wines (Maigre *et al*. 1995 ; Schwab *et al*., 1996 ; Löhnertz, 1998). Therefore, balancing shoot growth and fruit production is an important viticultural challenge. Because nitrogen is the most important factor for quality (Champagnol 1984), the impact of N fertilisation, such as the effect of the timing, rate and form of N fertilisation on vine physiology (e.g., vigour, yield) and grape quality (e.g., soluble solids, acidity, aromas) has often been studied (Rodriguez-Lovelle and Gaudillère, 2002 ; Holzapfel *et al*., 2007 ; Linsenmeier and Löhnertz, 2007 ; Neilsen *et al*., 2010). However, cases of N-deficient musts produced from vigorous grapevines have been observed along with symptoms of N deficiency in the leaves, despite a high level of N in the soil and an absence of significant water restriction (Spring, 2001). A theory has, thus, been proposed in which an excessive canopy development could lead to a decrease in the N content of the plant by dilution. To understand this phenomenon, two experiments on *Vitis vinifera* cvs. Chasselas and Pinot noir were carried out at the Agroscope Changins-Wädenswil (ACW) research station in Pully, Switzerland. The findings revealed in this report connect the impact of canopy manipulation – first, by lateral shoot removal and, second, by shoot trimming – on the accumulation of N in the vines and grapes.

MATERIALS AND METHODS

1. Study site and climate

The experiments were conducted in Pully (Geneva Lake, Switzerland), where the average temperature is 15.5°C during the growing period from April to October and the mean annual precipitation is 1140 mm, evenly distributed among the seasons (Pully, averages 1981-2010). During the period of experimentation from 2001 to 2010, the following years were relatively dry : 2003 (870 mm of precipitation), 2004 (935 mm), 2005 (802 mm), 2008 (992 mm), 2009 (877 mm) and 2010 (826 mm). Conversely, years 2001, 2002, 2006 and 2007 had above-normal average precipitation, with 1565, 1289, 1385 and 1 250 mm, respectively. The vineyard soil was composed of 17 % clay, 46 % sand and 4 % total calcium. The organic matter content was 1.7 %, and there was no deficiency in P, K, Mg or B.

2. Lateral shoot removal

The first trial was carried out between 2001 and 2004 on Chasselas cv. (clone 14/33-4) grafted onto rootstock 3309 C, which was planted in 1988 and trained in a single Guyot system. The planting density was 2x0.85 m, and the canopy height was 1,30 m. The lateral shoots were removed from the main shoots in the entire canopy ; in the control treatment, the lateral shoots were removed only in the fruit-bearing area (1/3 of the entire canopy) as per traditional management. Each treatment comprised 4 replicates (randomised blocks) of 32 vines each.

3. Shoot trimming

The second trial was carried out between 2001 and 2010 on the Chasselas cv. (clone ENTAV 31) and the Pinot noir cv. (clone RAC 12), both planted in 1999 and trained in a single Guyot system with a planting density of 1.50x0.80 m. The Chasselas and Pinot noir plots were separately organised in split-plot formations with 4 replicates of 33 vines, including a main treatment (3 canopy heights : 0.60 m, 1.00 m and 1.40 m) and a sub-treatment (3 rootstocks : 3309C, 5C and Riparia) for each cultivar. In the present report, only the influence of canopy height is discussed, and the results reflect the average of the three rootstocks. The shoot trimming was performed several times during the season to maintain the respective canopy heights for each treatment.

4. Measurements

The criteria of evaluation were based on the vegetative development (total leaf area and pruned wood weight), the mineral nutrition (chlorophyll index and leaf diagnosis), the yield components (bud fertility, bunch and berry weights and yield), and the composition of the must at harvest (soluble solids, total acidity, tartaric and malic acids and yeast available nitrogen). The total leaf area per vine was evaluated in each replicate by measuring on five different vines the total leaf area of the last shoot but one, according to Carbonneau's non-destructive method (1976), and then multiplying by the number of shoots per vine. For the leaf diagnosis, samples of 25 primary leaves (blade + petiole) were taken at veraison in the median part of the canopy of each replicate for the analysis of the levels of N, P, K, Ca and Mg (% dry weight). The yeast available nitrogen (YAN) level was measured in the must by the quantification of formaldehyde, as reported by Aerny (1996). The foliar N and must YAN both provided complementary information on the N nutrition of the grapevines at different growing stages (Gaudillère *et al*., 2003). Furthermore, the measurement of the chlorophyll index allowed the monitoring of the N fluctuation throughout the season and was performed in each replicate on 30 primary leaves of the median part of the canopy every 15 days during the growing season using an N-tester (Hydro Agri Deutschland GmbH). The yield was fixed at 6 bunches per vine in the first trial (lateral shoot removal) and at 4 bunches per vine for Chasselas and 6 bunches per vine for Pinot noir in the second trial (shoot trimming). Significant differences between the treatments were statistically determined using ANOVA and then Fisher's least significant difference (LSD).

RESULTS AND DISCUSSION

1. Effect of lateral shoot removal

a. Plant growth and leaf-fruit ratios

There were major differences concerning the vegetative development between the control and the vines that had all of their lateral shoots removed (table 1); the control demonstrated a conspicuous increase in pruned wood weight (+29 %) and total leaf area (+76 %). The leaf-fruit ratio was 1.35 m^2/kg in the control versus 0.98 m^2/kg in the vines that had all of their lateral shoots removed. It should be emphasised that the optimum leaf-fruit ratio (i. e., the total leaf area per kg of grape) should be above 1.5 m^2/kg for the optimum accumulation of soluble solids (Bertamini *et al*., 1991).

b. Nitrogen in leaves and musts

The total removal of the lateral shoots led to a significant increase in the N content of the leaves (by leaf diagnosis) (figure 1A) and musts (by YAN) (figure 1B). Moreover, the YAN content was strongly related to the water deficit between May and August during the 4 years of the trial: the higher the water restriction was, the lower the YAN content was, especially during 2003, when a

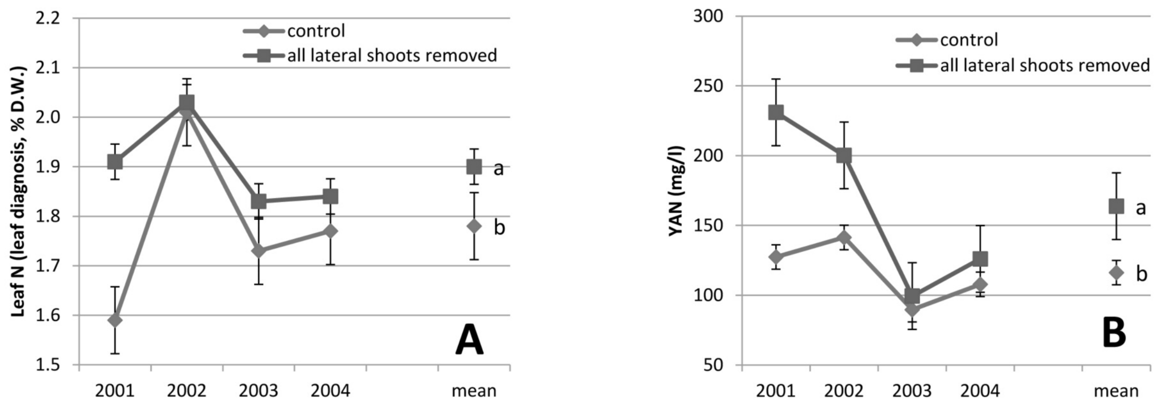

Figure 1 - Leaf N content at veraison (1A) (leaf diagnosis, % dry weight) and must N content (1B) (YAN, mg/l) per year and means of the four years. Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05). Trial 1, effect of lateral shoot removal on cv. Chasselas, Pully, 2001-2004. Bar = standard error.

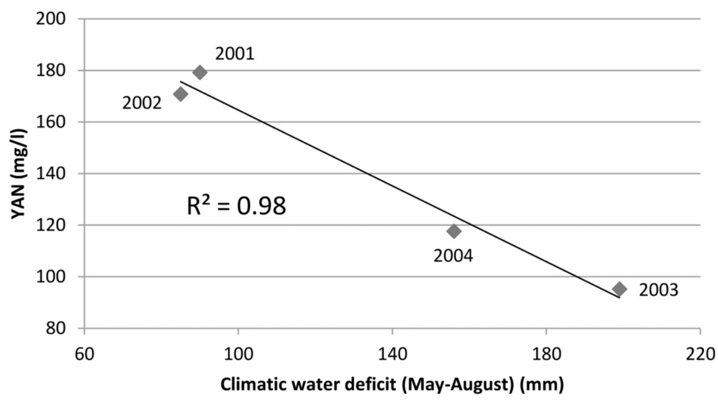

Figure 2 - Correlation between the seasonal climatic water deficit (May-August) (mm) and the must N content (YAN, mg/l). YAN values are averages of both treatment A and B. Trial 1, effect of lateral shoot removal on cv. Chasselas, Pully, 2001-2004.

Table 1 - Effect of lateral shoot removal on cv. Chasselas, Pully, means 2001-2004. Total leaf area (m^2/m^2 ground surface), pruned wood weight (g/vine), and leaf-fruit ratio (m^2/kg of grape) per treatment.
Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05).

Shoot removal Treatment	Total leaf area per m^2 of ground surface	Pruned wood weight g/vine	Leaf-fruit ratio Total leaf area/kg grapes
A. traditional shoot removal	1.65 (176%) a	564 (129%) a	1.35 a
B. total shoot removal	0.94 (100%) b	437 (100%) b	0.98 b

Table 2 - Effect of lateral shoot removal on cv. Chasselas, Pully, means 2001-2004. Yield and must components per treatment.
Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05).

Shoot removal Treatment	Yield components				Must components				
	Fertility Clusters / shoot	Berry weight g	Cluster weight g	Yield kg/m^2	Sugar °Brix	Total acidity g/l as tart. acid	Tartaric acid g/l	Malic acid g/l	pH
A. traditional shoot removal	1,94	3.14 a	348 a	1.22 a	18.2 a	6,1	5,7	2,7	3,39
B. total shoot removal	1,83	2.84 b	293 b	0.96 b	17.4 b	6,3	5,8	3	3,41

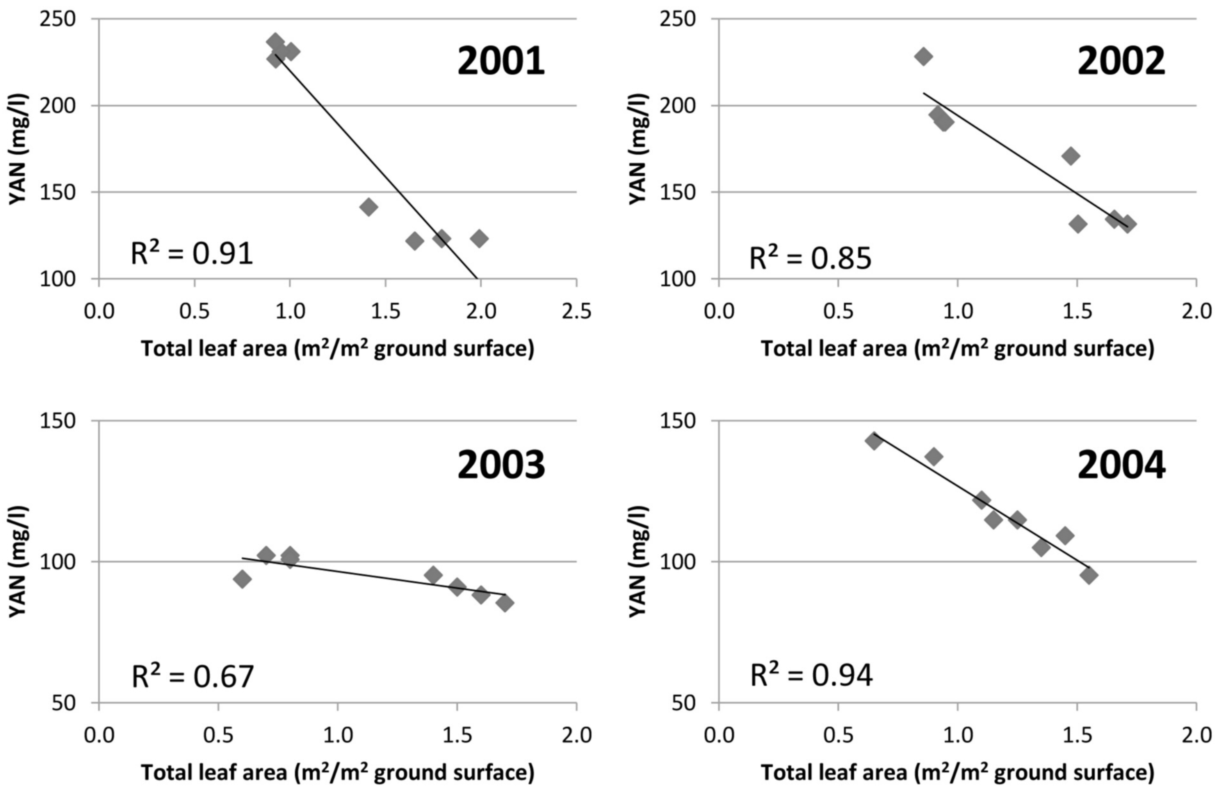

Figure 3 - Correlations between the total leaf area (m^2/m^2 ground surface) and the must N content (YAN, mg/l) for each year. Trial 1, effect of lateral shoot removal on cv. Chasselas, Pully, 2001-2004.

200-mm water deficit occurred between May and August (figure 2). As a consequence, differences in the YAN levels between treatments were more noticeable during those years with lower water restriction (2001 and 2002). In this experiment, the leaf N rate was low in both treatments according to the leaf diagnosis thresholds (Spring *et al*., 2003). In the control, the YAN content in the must was always very low, under 140 mg/l of N. In contrast, the vines that had all of their lateral shoots removed presented higher values, above 195 mg/l in 2001 and 2002, which then declined in 2003 and 2004 due to the drier weather conditions. For each year of the experiment, the total leaf area and YAN content in the musts were negatively correlated (figure 3). Moreover, the measurement of the chlorophyll index was monitored between 2002 and 2004 and was found to be higher in the vines that had all of their lateral shoots removed than in the control. Such differences were, however, less noticeable in 2003 when the plants experienced increased water restriction, which resulted in a reduction in the N assimilation (figure 4).

c. Yield components and must composition

In comparison to the control and despite a higher N content, the treatment that removed the lateral shoots resulted in a lower fertility, a lower berry weight, smaller bunches and a lower soluble solid content, and, thus, the yield was lower (table 2). These findings could be primarily explained by the leaf-fruit ratio difference between the treatments. Indeed, Bertamini *et al*. (1991) have studied the correlation between the quantity of soluble solids in the must and the total leaf area and have reported that a maximum level of soluble solids was obtained in the must for a leaf-fruit ratio of 1.5 m²/kg ; a similar relationship was observed in the present study (figure 5). Therefore, a leaf-fruit ratio of 0.98 m²/kg, as in the vines that had all of their lateral shoots removed, would be expected to lead to a lower amount of soluble solids.

2. Effect of shoot trimming

a. Plant growth and leaf-fruit ratios

For both the Chasselas and Pinot noir cvs., the pruned wood weight increased by approximately 50 % when the canopy height was changed from 60 cm to 100 cm, and it increased by 100 % when the canopy height was changed from 60 cm to 140 cm (table 3). In addition, the total leaf area increased significantly in inverse proportion to the trimming severity. For both cultivars, the leaf-fruit ratio was too low when the canopy was reduced to 60 cm (0.62 and 0.89 m² of total leaf area per kg of fruit, respectively), was balanced when the canopy was 100 cm (1.26 and 1.55 m²/kg, respectively) and was excessive when the canopy was 140 cm (1.67 and 2.37 m²/kg, respectively) (table 3).

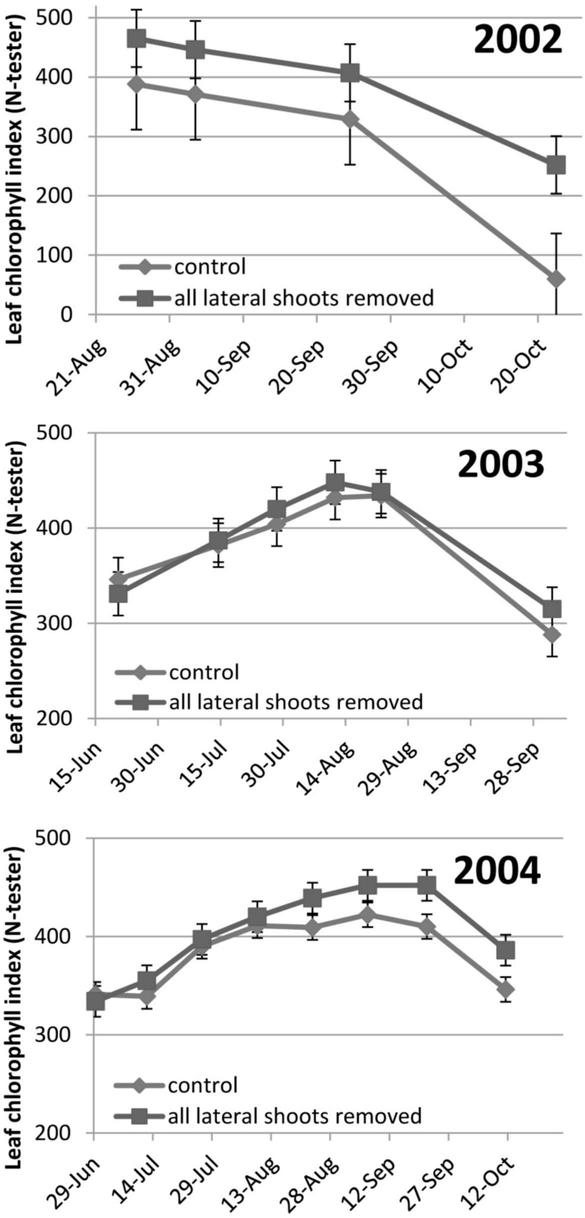

Figure 4 - Evolution of the leaf chlorophyll (N-tester Index) throughout the seasons.
Trial 1, effect of lateral shoot removal on cv. Chasselas, Pully, 2002-2004. Bar = standard error.

b. Nitrogen in the leaves and musts

The leaf N content was inversely proportional to the canopy height for both the Chasselas and Pinot noir cvs. (figure 6). Similarly, the YAN content in the must was inversely proportional to the canopy height (figure 7). As observed in the first trial, the YAN content was universally lower when the water deficit was greater, especially in 2003, 2005 and 2009 with 200, 230 and 240 mm of water deficit, respectively. The total leaf area was negatively correlated with the YAN content in the must for both

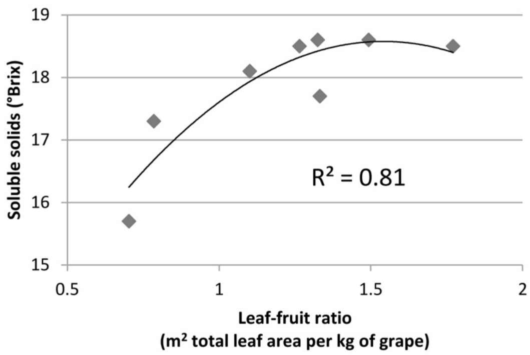

Figure 5 - Correlation between the leaf-fruit ratio (total leaf area/kg of fruit) and the must soluble solid content (g/l). 4-year means for each replicate. Trial 1, effect of lateral shoot removal on cv. Chasselas, Pully, 2001-2004.

cultivars (figure 8). Finally, the chlorophyll index was monitored only for the Pinot noir cv. during 2005, as the monitoring of the Chasselas vines was impossible due to symptoms of Mg deficiency. The highest canopy (140 cm) was distinguished by a lower chlorophyll content and a more rapid regression of the chlorophyll index by the end of the growing season (figure 9).

c. Yield components and must composition

Differences between treatments were less obvious than in the first trial. Soluble solid content was nevertheless significantly lower in treatment with the lowest canopy (60 cm) in comparison to the highest canopy (140 cm) with more than 0.5°Brix difference in the case of cv. Chasselas (table 4).

CONCLUSION

For both trials, all three of the indicators of the N content in the vines (i. e., leaf diagnosis, the YAN content and the chlorophyll index) distinctly implicated the effect of canopy management – either lateral shoot removal or shoot trimming – on the N content in the leaves and must. Clearly, this result was less obvious during the 2003 and 2004 seasons due to the water restriction that limited the N uptake by the plants. Overall, under non-restrictive water conditions, the leaf area development can be excessive and can lead to a reduction of the N concentration – in the leaves and in the grapes – due to an effect of the dilution of N throughout the canopy. This dilution can, as a consequence, induce both N deficiency in the plant and YAN deficiency in the must. Indeed, wines can suffer from a YAN deficiency in the must and be penalized in wine tastings, as yeasts require a minimum amount of 140 mg of YAN per liter to prevent fermentation problems and wine depreciation (Lorenzini, 1996, Christoph *et al*., 1995). The present trial was focused on understanding the reasons of low N concentrations in the grapes and the final quality of the musts issued from vigorous vines. These results pointed out the relation of competition between the canopy development and YAN accumulation in the grapes. It would be interesting to complete these results with the assessment of the total N content on the entire vine and its distribution between the different organs of the plant, according to the canopy size. On the contrary, insufficient leaf area development can lead to a reduced photosynthesis, which negatively affects both the maturation of the grapes (lower soluble solid concentration) (Keller, 2010) and the reconstitution of starch reserves (Koblet *et al*., 1993). Depending on the local conditions (e.g., climate, soil, and cultivar) and the prospective yield, especially in a situation under which N may be restricted, the optimum canopy size should be attained to approach a balanced leaf-fruit ratio to allow a proper grape maturation and a proper YAN content in the must as much as possible. From this perspective, Murisier (1996) has proposed a minimum of 1.0 to 1.2 m^2 of exposed leaf area per kg of fruit for proper grape maturation. In conclusion, canopy management is a

Table 3 - Effect of shoot trimming on cvs. Chasselas and Pinot noir, Pully, 2005. Total leaf area (m^2/m^2 soil surface), pruned wood weight (g/vine), and leaf-fruit ratio (m^2/kg of grape) per treatment and per cultivar. Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05).

Cultivar	Shoot trimming Treatment	Total leaf area per m^2 of ground surface	Pruned wood weight g/vine	Leaf-fruit ratio Total leaf area / kg grapes
Chasselas	A. 60 cm	0.70 (100%) c	265 (100%) c	0.62 c
	B. 100 cm	1.32 (189%) b	407 (154%) b	1.26 b
	C. 140 cm	1.85 (264%) a	524 (198%) a	1.67 a
Pinot noir	A. 60 cm	0.85 (100%) c	275 (100%) c	0.89 c
	B. 100 cm	1.57 (185%) b	408 (148%) b	1.55 b
	C. 140 cm	2.24 (264%) a	523 (190%) a	2.37 a

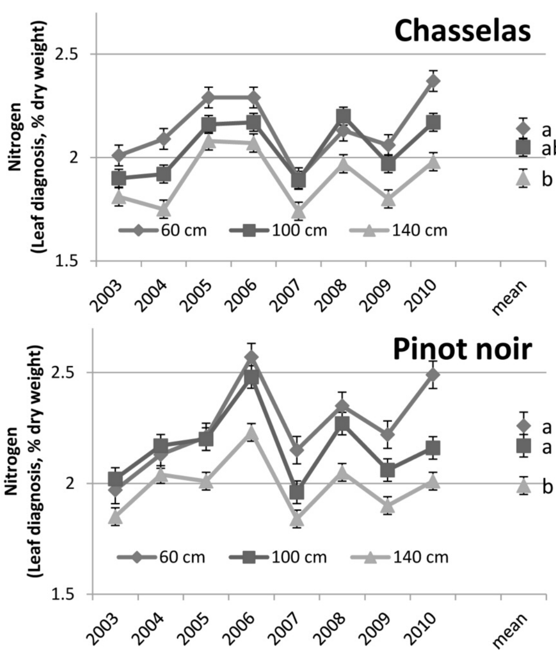

Figure 6 - Leaf N content at veraison (leaf diagnosis, % D.W.) per year and means of the eight years. Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05). Trial 2, effect of shoot trimming on cvs. Chasselas and Pinot noir, Pully, 2003-2010. Bar = standard error.

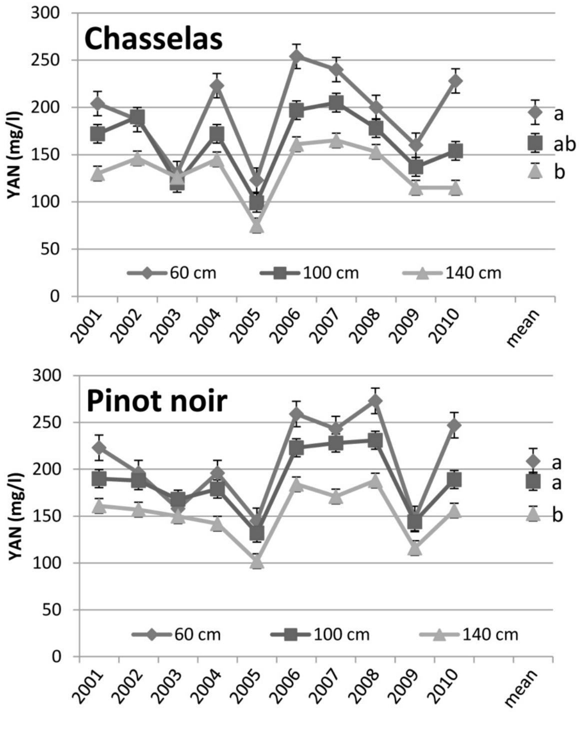

Figure 7 - Must N contents (YAN, mg/l) per year and means of the ten years. Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05). Trial 2, effect of shoot trimming on cvs. Chasselas and Pinot noir, Pully, 2001-2010. Bar = standard error.

determining element in the reduction of N deficiency in both vines and in grapes.

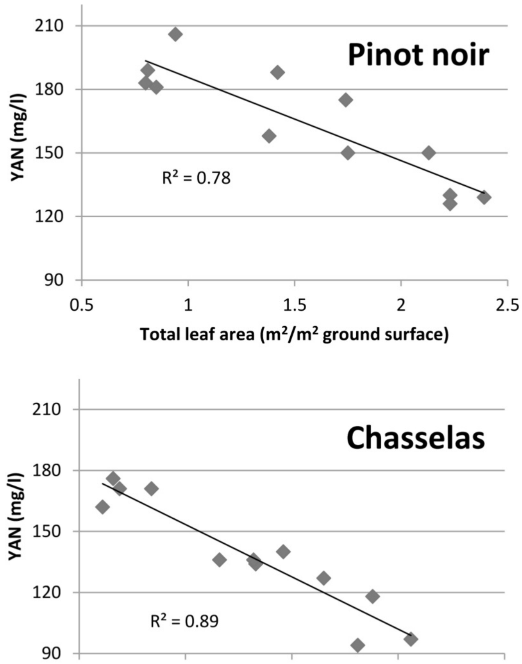

Figure 8 - Correlations between the total leaf area (m^2/m^2 soil surface) and the must N content (YAN, mg/l). Trial 2, effect of shoot trimming on cvs. Chasselas and Pinot noir, Pully, 2001-2010.

REFERENCES

Aerny J., 1996. Composés azotés des moûts et des vins. *Rev. suisse Vitic. Arboric. Hortic.* **28** (3), 161-165.

Bertamini M., Iacono F. and Scienza A., 1991. Manipulazione dei rapporti sink-source mediante il diradamento dei grappoli e riflessi sulla qualità (cv. Cabernet Sauvignon). *VigneVini* **10**, 41-47.

Carbonneau A., 1976. Principe et méthodes de mesure de la surface foliaire. Essai de caractérisation des types de feuilles dans le genre *Vitis*. *Ann. Amél. Plantes,* **26** (2), 327-343.

Champagnol F., 1984. *Éléments de physiologie de la vigne et de viticulture générale*. Ed. Champagnol, 351 p.

Christoph N., Bauer-Christoph C., Gessner M., Köhler H.J., 1995. Die "Untypische Alterungsnote" im Wein. Teil 1: Untersuchungen zum Auftreten und zur sensorischen Charakterisierung der "Untypische Alterungsnote". *Rebe und Wein*, **9**, 350-356.

Crespy A., 2007. *Manuel pratique de fertilisation, qualité des moûts et des vins*. Collection Avenir Œnologie, 143p.

Gaudillère J.-P., Chantelot E., Soyer J.-P., Molot C., Milin S., 2003. L'azote des feuilles et des moûts, deux indicateurs complémentaires pour évaluer le statut azoté de la vigne. *J. Int. Sci. Vigne Vin*, **37** (2), 91-101.

Table 4 - Effect of shoot trimming on cvs. Chasselas and Pinot noir, Pully, 2001-2006. Yield and must components per treatment and per cultivar. Values followed by a different letter are significantly different according to Fisher's LSD (P<0.05).

Cultivar	Shoot trimming Treatment	Yield components				Must components				
		Fertility Clusters / shoot	Berry weight g	Cluster weight g	Yield kg/m^2	Sugar °Brix	Total acidity g/l as tartaric acid	Tartaric acid g/l	Malic acid g/l	pH
Chasselas	A. 60 cm	1,81	2,92	325	1,22	17.8 b	5,6	5.4 a	2,6	3,43
	B. 100 cm	1,67	2,96	358	1,21	17.9 b	4,8	5.3 a	2,2	3,43
	C. 140 cm	1,85	3,05	321	1,2	18.2 a	5,1	5.1 b	2,3	3,43
Pinot noir	A. 60 cm	1,78	1,50	215	1,06	21.7 b	9,6	6,7	4.8 b	3,16
	B. 100 cm	1,83	1,55	218	1,07	22.1 a	9,6	6,5	5.0 a	3,16
	C. 140 cm	1,82	1,58	207	1,03	22.1 a	9,8	6,5	5.1 a	3,14

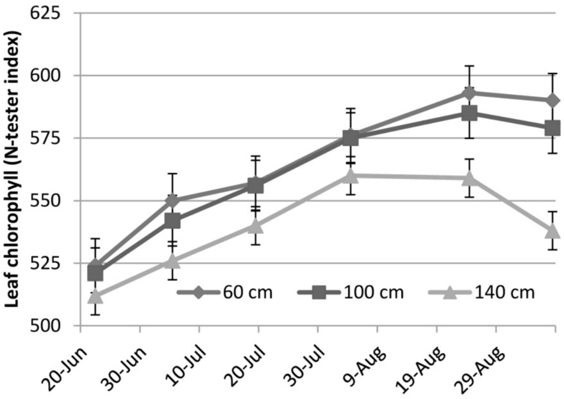

Figure 9 - Evolution of the leaf chlorophyll (N-tester Index) throughout the season. Trial 2, effect of shoot trimming on cv. Pinot noir, Pully, 2005. Bar = standard error.

Holzapfel B. P. and Treeby M. T., 2007. Effects of ti Holzapfel B. P. & Treeby M. T., 2007. Effects of timing and rate of N supply on leaf nitrogen status, grape yield and juice composition from Shiraz grapevines grafted to one of three different rootstocks. *Aus. J. Grape Wine Res.*, **13** (1) 14-22.

Hopkins W. G., 2003. *Physiologie végétale*. Ed. De Boeck & Larcier, 514 p.

Keller M., 2010. *The science of grapevines: Anatomy and physiology*. Ed. Academic press, Elsevier, 377 p.

Koblet, W., M.C. Candolfi-vasconcelos, E. Aeschimann, G.S. Howel. 1993. Influence of defoliation, rootstock and training system on Pinot noir grapevines. I. Mobilization and reaccumulation of assimilates in woody tissue. *Vitic. Enol. Sci.*, **48**, 104-108.

Linsenmeier A. and Löhnertz O., 2007. Einfluss der Stickstoffdüngung auf Wuchs, Ertrag, Most- und Weinqualität der Sorte Riesling in einem zwanzigjährigen Langzeitversuch. II: Von der Traube zum Wein. *Mitteilungen Klosterneuburg, Rebe und Wein, Obstbau und Früchteverwertungm*, **57** (1), 37-50.

Löhnertz O., 1998. Begrünung und Weinqualität in "Gesunder Boden durch Begrünung". *Compte-rendu 5^e Symp. int. "Technik im Weinbau"*, Stuttgart, Allemagne, 12 au 13 mai 1998, 101-112.

Lorenzini F., 1996. Teneur en azote et fermentescibilité des moûts. *Revue suisse Vitic. Arboric. Hortic.*, **27**, 237-251.

Maigre D., Aerny J. and Murisier F., 1995. Entretien des sols viticoles et qualité des vins de Chasselas : influence de l'enherbement permanent et de la fumure azotée. *Rev. suisse Vitic. Arboric. Hortic.*, **27**, 237-251.

Murisier F., 1996. Optimalisation du rapport feuille-fruit de la vigne pour favoriser la qualité du raisin et l'accumulation des glucides de réserves. Relation entre le rendement et la chlorose. *Thèse Doctorat*, EPFZ Zürich.

Neilsen G. H., Neilsen D., Bowen P., Bogdanoff C. and Usher K., 2010. Effect of timing, rate, and form of N fertilization on nutrition, vigor, yield and berry yeast-assimilable N of grape. *Am. J. Enol. Vitic.*, **61** (3), 327-336.

Rodriguez-Lovelle B. and Gaudillère J.-P., 2002. Carbon and nitrogen partitioning in either fruiting or non-fruiting grapevines: effect of nitrogen limitation before and after veraison. *Aust. J. Grape Wine Res.*, **8** (2), 86-94.

Schwab A. L., Peternel M., Köhler J. and Hergel K.-P., 1996. Die untypische Alterungsnote im Wein. *Rebe und Wein,* **6**, 181-187.

Spring J.-L., 1999. Indice chlorophyllien du feuillage et nutrition azotée du cépage Chasselas. Premières expériences en Suisse romande. *Rev suisse Vitic., Arboric., Hortic.* **31** (3), 141-145.

Spring J.-L. and Zufferey V., 2000. Intérêt de la détermination de l'indice chlorophyllien du feuillage en viticulture. *Rev. suisse Vitic. Arboric. Hortic.* **32** (6), 323-328.

Spring J.-L., 2001. Influence du type d'enherbement sur le comportement de la vigne et la qualité des vins. Résultats d'un essai sur Chasselas dans le bassin lémanique. 1. Résultats agronomiques. *Rev. suisse Vitic. Arboric. Hortic.,* **33** (5), 253-260.

Spring J.-L., Ryser J.-P., Schwarz J.-J., Basler P., Bertschinger L. and Häseli A., 2003. Données de base pour la fumure en en viticulture. *Rev. suisse Vitic. Arboric. Hortic.*, **35** (4).