Effect of vine nitrogen status on grape and wine quality:
Terroir study in the Vaud vineyard (Switzerland)

J-S Reynard[(1)], V. Zufferey[(1)], F. Murisier[(1)]
[(1)]Agroscope Changins-Wädenswil ACW, CH-1260 NYON (Switzerland)
Corresponding author: jean-sebastien.reynard@acw.admin.ch

Abstract

This study was conducted on soil-climate-plant relations (terroir) and their impact on grape composition and wine quality in the canton of Vaud by Agroscope Changins-Wädenswil ACW. An assessment of the vine nitrogen status on different terroirs was made by means of chlorophyll index, leaf nitrogen content and yeast assimilable nitrogen. Vine nitrogen status was observed to be highly related to soil type. Vines on the soil type "bottom moraines" showed lower vigour, smaller berries and a lower nitrogen status. Sensory analysis discriminated wines from different soil types. Vine nitrogen status through yeast assimilable nitrogen turned out to be strongly correlated with wine positive sensory descriptors and negatively correlated to wine astringency. In our study, the main environmental factors influencing vine development and wine quality was the soil type via its effect on vine nitrogen level. Our results confirm the role on nitrogen supply in grape and wine quality and underline nitrogen as a key factor in understanding the terroir effect.

Key-words: Soil component of terroir – vine nitrogen status – ecophysiology – grape and wine quality

Introduction

Nitrogen is one of the mineral element that grape requires in greatest amount. Therefore, it is one of the most influent mineral nutrients on the physiology of the grapevine. Vine development, yield, fruit composition and wine quality are highly related to the vine nitrogen status.
N fertilisation increases vigour, resulting in modification of canopy microclimate (Smart *et al.,* 1991) and a higher sensibility to *Botrytis cinerea.* Spayd *et al.* (1994) reported that grapes with an elevated level of N showed delayed fruit ripening and produce wine with a higher pH. Vine nitrogen status has been showed to affect tannin and anthocyans content from grapes (Tregoa *et al.,* 2002). Nitrogen nutrition does impact the amount of aromatic compounds or precursors in grapes (Peyrot des Gachons *et al.,* 2005).
Most studies reported in the literature on nitrogen have been conducted as fertilisation trials, where different N supplies (often large amounts) where given to vines. Indeed, the present work aims to study the impact of environmental factors itself (mainly climate and soil) on vine. In viticulture those natural factors are known under the concept of "terroir". We are investigating the most pertinent parameters of terroir which are responsible for grape and wine quality. A better understanding of the terroir effect will help vine-growers in their vineyard management (irrigation, fertilisation, rootstocks and grape cultivars). Among those parameters, this article will focus on vine nitrogen status affected by soil variation. The present results are part of a wider study on the various "terroirs" in the Canton of Vaud and how they affect grape and wine quality. This wider project is conducted on 130 locations distributed on the entire Vaud vineyard (3800 ha) and endeavours to evaluate the adaptation of 10 grape cultivars to the different region's terroirs.

Materials and Methods

1. Experimental sites

A network consisting of 12 locations was set up in a viticultural region of Vaud named "La Côte". Locations have been chosen in order to represent the pedo-climatic conditions from the region. The study sites were planted with *Vitis Vinifera* L. cv. Doral (Chasselas X Chardonnay) in 2003, therefore studied vines have the same age all over the plots. Each site had a surface of circa 200 m^2 and was located in the middle of a wider commercial vineyard.

All vines were grafted onto 3309C rootstock and trained in espalier (single Guyot with vertical shoot positioned foliage). The average plantation density was 6'400 vines/ha.

The nonirrigated plots were cultivated by the winegrowers. Yield was limited by clusters thinning at berries pea-sized. Average yield was 10 t/ha. The leaf area/fruit weight ratio was over 1 m^2/kg. Agronomical practices (fertilization and pest control) were similar between locations. Floor management was permanent sod each two rows with herbicided strips under the vines.

2. Soil and climate characteristics

a) Soil types

An earlier soil study of the viticultural areas of Vaud has enabled to classify the different soils resulting in a map of pedological units. The studied locations are situated on representative geological units of the region. The majority of soils in the study area were made up of alpine moraines, a heterogeneous mixture of unevenly sized debris transported by the Rhone glacier during the last glaciation (100'000-10'000 years BC). Moraines can be grouped into three types (Letessier *et al.,* 2004): lateral moraines, bottom moraines and retreating moraines. Lateral moraines were formed at the glacier's lateral edges. Bottom moraines originate from materials which were located underneath the glacier and underlay great pressure. Soils which belong to that category show a high compactness. Retreating moraines were formed during the melting phase of the glacier. The main characteristics of the different moraines are summed up in **Table 1**. Some colluvial deposits found at the foot of slopes originate from progressive erosion of the dominating slopes. They contain few coarse elements (0-20%). We regrouped the different soil types in two categories, namely bottom moraines (7 locations) and other soil types (5 locations). This decision was motivated by the fact that the category "other soil types" did present a consistent physiological behaviour (see Results).

Soil type	Coarse elements	Compactness	Clay content	active limestone
Lateral moraine	30-60 %	porous	10-18%	4-7 %
Bottom moraine	10-30 %	very high	12-25 %	7-12%
Retreating moraine	60-90 %	porous	5-10 %	2-7 %

Table 1 Basic properties of moraine soils (Letessier *et al.,* 2004)

b) Climatic conditions of years 2007 and 2008

Climatic parameters were supposed to be homogenous on our 12 locations, since they were situated no more than 60 km away from each other. The year 2007 was characterised by very heavy rainfall between Mai to August. Summer months were cooler in average. April of the same year had very few precipitation events and average temperature was high. The 2008 vintage corresponded to an average vintage in the region. Frequent and abundant rainfalls were recorded in the late growing season (September to October).

3. Experimental measurements

a) Vine nitrogen status

The vine nitrogen status was assessed using three different indicators: foliar analysis (at veraison, % of dry matter), chlorophyll index (N-Tester, Yara, France) and yeast assimilable nitrogen (Aerny, 1996).

b) Berry composition

Fruit maturation was monitored on every site each 2 weeks from veraison to harvest. The main analytical parameters (sugars, acids and yeast assimilable nitrogen) were measured on 200 berries samples using the WineScan® (FOSS NIRSystems, USA).

c) Miocrovinification

Microvinification was conducted identically for all lots by the same winemaker. For each terroir 150 kg of grape were harvested within one week. 0.3 gr/L of diammonium phosphate (DAP) was added to each must to aid the completion of the fermentation.

Results

1. Water status

For both years, the average predawn water potential measured on various sites never went lower than 0.3 MPa, which corresponds to the critical value for low water stress. Furthermore, analyses of carbon isotope discrimination (Gaudillère *et al.,* 2002) on musts gave values ranging from -27.7‰ to -25.2‰. These results show that water supply was sufficient for all the sites during the 2 vintages and therefore water availability didn't interact with fruit quality on those two vintages.

2. Nitrogen status

The chlorophyll content was monitored through 2 growing seasons (**Figure 1**). During the 2008 vintage, chlorophyll content was increasing steadily up until 2 months after flowering. On the other hand, in 2007, it remained nearly constant after flowering, and then began, nearly 3 months after flowering, to fall down sharply. On both vintages, vines on bottom moraines did present, in average, a lower content of chlorophyll compare to other soil types.

Leaf diagnostic was carried out at veraison stage to determine possible mineral deficiency. Leaf nitrogen content at veraison was significantly lower for vines established on bottom moraines in 2007 and 2008 (**Figure 1**). Leaf nitrogen content was superior during the 2008 vintage whatever the soil type. No other noticeable differences were observed for the other minerals.

Yeast assimilable nitrogen (YAN) in musts was monitored from veraison to harvest (**Figure 2**). Vines growing on bottom moraines had low nitrogen content in musts. Difference between the two soil categories was more noticeable in 2007, where nitrogen status of vines on bottom moraines was systematically under the other ones. On the other hand, during the 2008 vintage, the difference was less obvious, 3 measures out of 5 turned to be significantly different. YAN tended to be higher in 2008 compare to 2007.

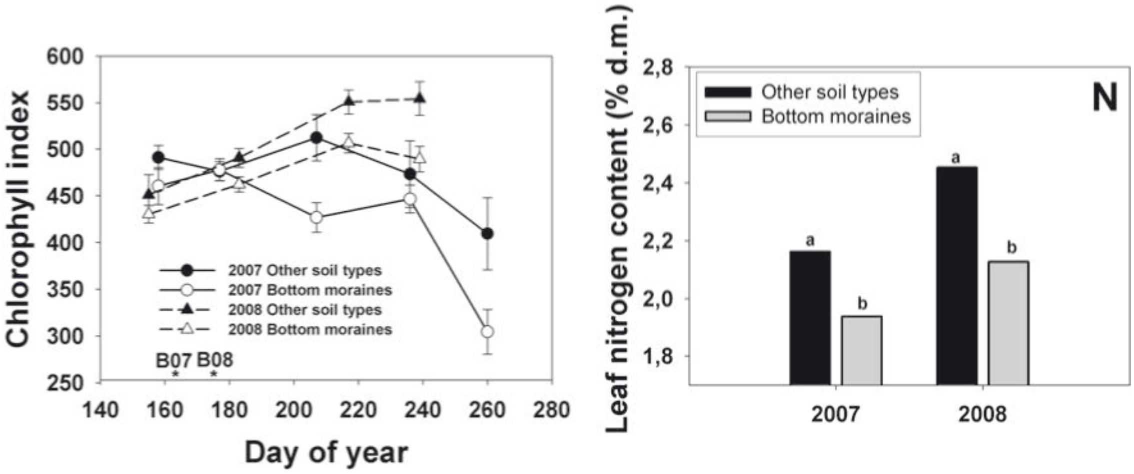

Figure 1 *Left: Seasonal evolution of the SPAD index from two vintages 2007 and 2008 and two categories of soil types. Vertical bars indicate standard error of means. B07, B08 are the bloom time for each vintage. Right: Nitrogen content of leaves at veraison expressed as % of dry matter. Means with different letters are significantly different (Duncan's test, P<0.01).*

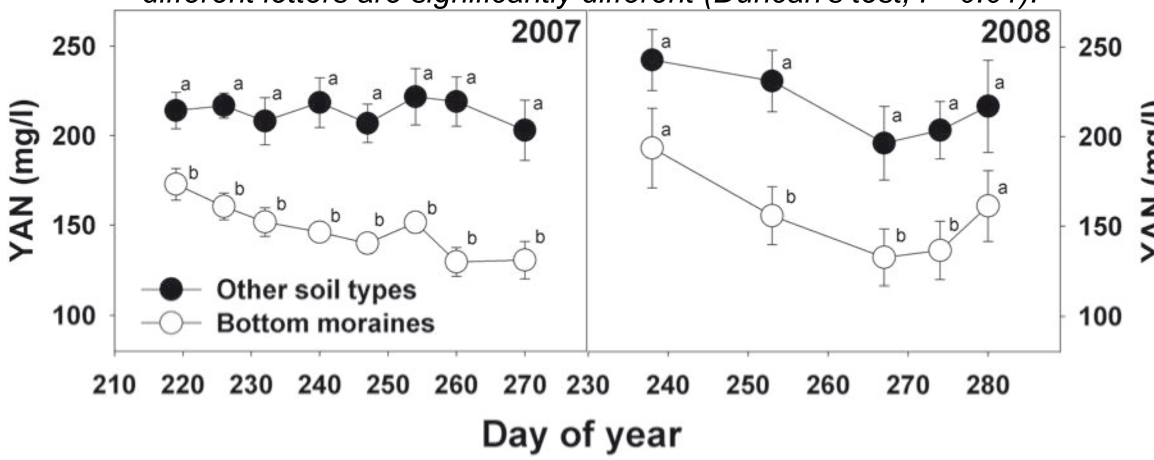

Figure 2 *Seasonal evolution of yeast assimilable nitrogen (YAN) in grapes as affected by soil types during the 2007 and 2008) vintage. The last data points correspond to harvest. Vertical bars indicate standard error of means. For the same date, means foiowed by the same letter are not significantly different at P<5% according to Duncan test.*

A principal component analysis (PCA) was run on the several physiological variables measured on each location (**Figure 3**). Those variables include indicators of vine vigour, vine mineral status, phenology and must composition. Data about phenology are depicted only for the 2008 vintage, since no data were recorded in 2007. PCA provides a visualization of the relation between the physiological variables (**Figure 3A** and **3C**) and a two-dimensional map of the locations (**Figure 3B** and **3D**). The first dimension is linked to nitrogen parameter, vine vigour and must acidity. Those variables are correlated. Yeast assimilable nitrogen was well correlated with vine vigour indicators (weight of pruned branches: r = 0.6 significant at α=0.05, berries weight: r = 0.82 significant at α=0.001).

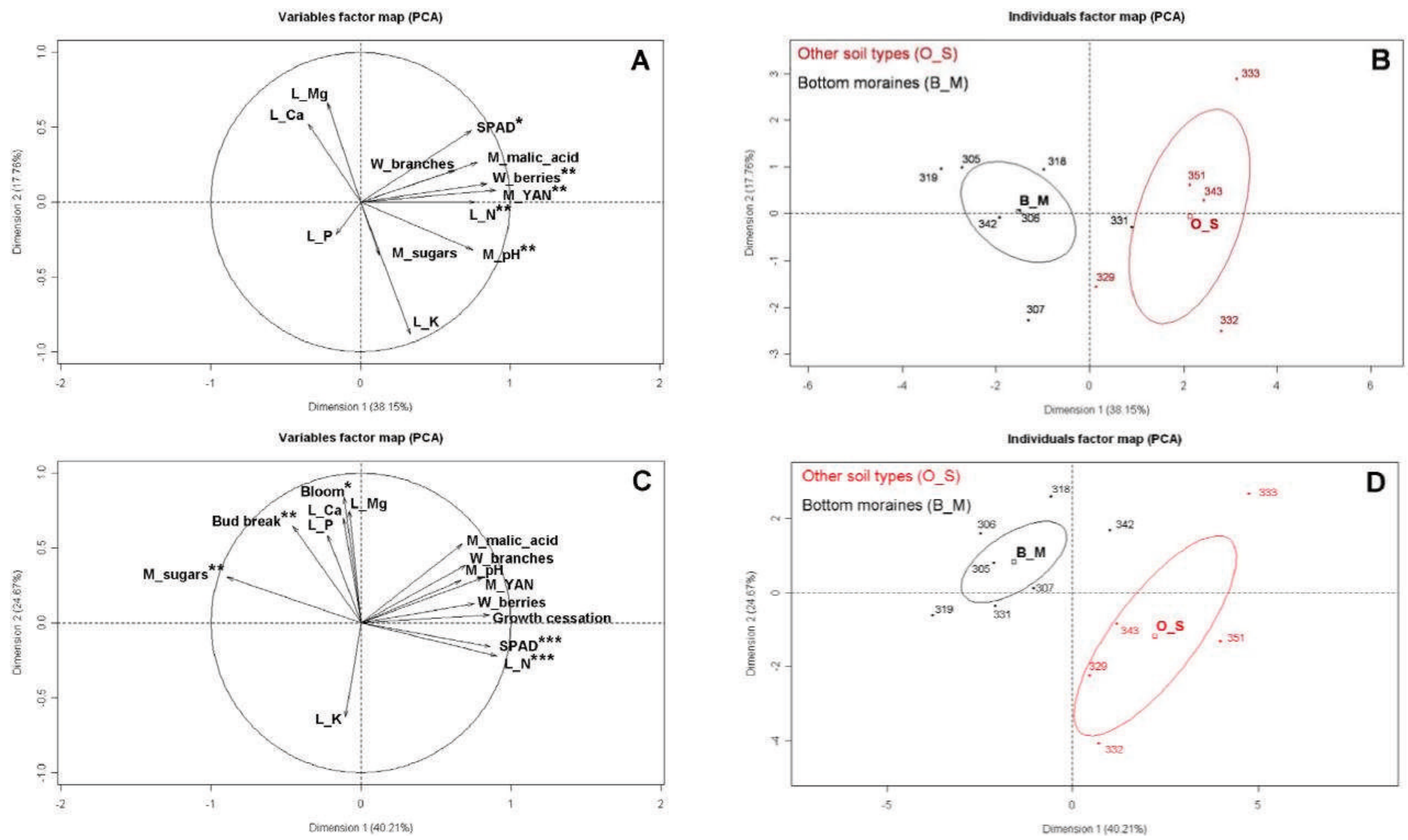

Figure 3 Representation of grape physiology variables (A, C) by using PCA approach on two vintages (2007: A, B; 2008: C, D). On Figure 5A and 5B, asterisks indicate variables which are significantly different between the 2 soil categories (Duncan's test at 5% (*), 1% (**) and 1‰ (***)). Locations are represented (C, D) on the first 2 dimensions of PCA and colored according to their soil types. Location code stands beside each data point. Barycentres of the two soil categories are depicted with their confidence interval at 95%.

M_variables are measured on must at harvest, W_ branches= weight of pruned branches, L_variables represent leaf minerals content at veraison, M_YAN=yeast assimilable nitrogen in must, SPAD=season-average chlorophyll content, Bud break= date (day of year) of bud break, Bloom = date (day of year) of bloom, Growth cessation = date (day of year) of shoot growth cessation.

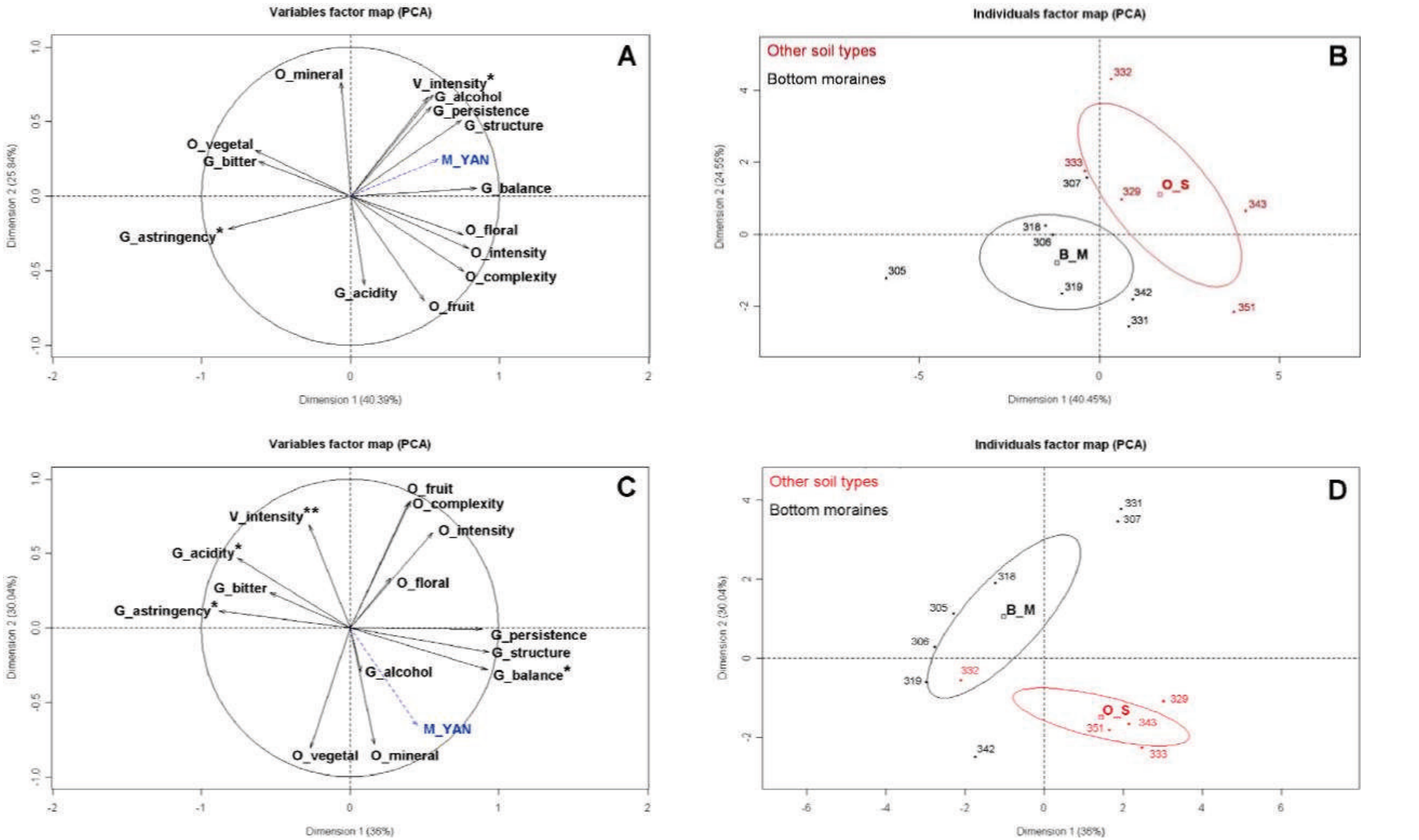

Figure 4 PCA Representation of the main sensory variables evaluated on the 12 locations' wines from the 2007 (A) and 2008 vintage (C). Yeast assimilable nitrogen (M_YAN) was added as illustrative variable. Asterisks indicate variables which are significantly different between the 2 soil categories (Duncan's test at 5% (*) and 1% (**)). Locations' wines are represented (2007: B; 2008: D) on the first 2 dimensions of PCA and colored according to their soil types. Barycentres of the two soil categories are depicted with their confidence interval at 95%. Sensory variables: V_=visual, O_=olfactory, G_=gustatory

On the individuals map (**Figure 3B**), first axis distinguishes significantly locations according to their soil type. Vines on bottom moraines showed weaker vigour, lower nitrogen content in leaves and berries and their musts were more acid compare to other soil types.
In 2008, as shown in **Figure 3C**, the first dimension of the PCA analysis was positively correlated with vine vigour, nitrogen status, must's acidity (pH and malic acid content) and the day of year of apex growth cessation. The amount of sugars in must at harvest was negatively correlated with vine vigour, vine nitrogen status and apex growth (weight of pruned branches: r=-0.86 significant at α=0.01, leaf nitrogen: r=-0.92 significant at α=0.001, growth cessation: r=-0.73 significant at α=0.01). Bud break and bloom were linked to the second dimension of the PCA. On the individuals (locations) map (**Figure 3D**), the two soil categories can be discriminated mainly along the F1 axis. During the 2008 vintage, vines growing on bottom moraines had a lower nitrogen status and their grapes reached higher sugar content at harvest compare to vines growing on other soil types. Furthermore, locations which belong to the category "other soil types" showed vine precocity from bud break (average of 5.5 days earlier) and bloom (average of 2 days earlier).

As for the physiological variables, a principal component analysis was carried out on data from wine sensory analysis (**Figure 4**). YAN in must has been added to PCA analysis as illustrative variable. For the vintage 2007, YAN points on the same direction than positive sensory descriptors such as gustatory persistence and structure (**Figure 4A**). YAN was observed to be strongly negatively correlated to the sensory astringency perceived in wine by our panel (r = 0.89 significant at α=0.001). Wines produced from location situated on bottom moraines were judged astringent and tended to show lower colour intensity (**Figure 4B**). On the 2008 vintage, no significant correlation was detected between YAN in the musts and wine astringency (**Figure 4C**). Locations which were not situated on bottom moraines gave wine more balanced (**Figure 4D**). On the other hand, vine from bottom moraines were assessed to be more acid, astringent and showed greater colour intensity. For both vintages, wines from the 2 different soil types were discriminated by our panel during sensory analysis sessions. On both vintages, wine produced on bottom moraines were characterized as astringent and were assessed less structured and balanced.

Discussion

It is generally accepted that some sort of stress (mainly mineral deficiency or water limitation) is beneficial for fruit composition and wine quality (Keller *et al.,* 2005; Van Leuween *et al.,* 2004). Water supply to vines was abundant in our study due to regular rainfall. Therefore, no water limitation was observed for the 2 vintages on the studied vines. But on the other hand, vines did show a differentiate nitrogen supply according to vintage and soil types. Nitrogen status of vines was higher in 2008 compare to 2007 (**Figure 1 and 2**). Musts from vines on bottom moraines had a YAN average slightly under 140 mg/l at harvest, in 2008, the YAN of the same category were over 160 mg/l. 140 mg/l is generally considered to be the under limit of nitrogen content in must in order to avoid a stuck fermentation (Butzke, 1998). The difference in nitrogen supply on these 2 vintages could be explained by the exceptional climatic conditions of the 2007 vintage. The summer 2007 was extremely rainy and with lower temperature. These adverse conditions might have interfered with absorption and assimilation of nitrogen (root asphyxiation). This hypothesis is supported by the observation of early senescence of basal leaves (yellowing and shedding) around veraison detected in 2007 only.

On both vintages, must nitrogen was related to the content of malic acid in the berries at harvest. This relation can be explained through vine vigour, having a higher N supply, vine would growth a denser canopy and thus affecting the microclimate (temperature and sun exposition) of grapes and leading to a lower degradation of malic acid in the berries. Must pH increased linearly with increasing nitrogen compounds in berries (YAN), we observed good correlation on the 2 vintages between YAN and must pH (2007: r = 0.68; 2008: r = 0.63, both significant at α = 0.05). Similar results have been obtained by Spayd *et al.* (1994).

N status of vine was highly dependant on soil type (**Figure 1 and 2**). Bottom moraines are very compact (Letessier *et al.,* 2004), thus it's probably difficult for plants to colonize those soils and to establish their root system. As a consequence grapes grown on that soil type showed minor vigour, smaller berries and, when nitrogen supply is not too severe (like during 2008), greater amount of sugars. Vegetative period was shorter for vines on bottom moraine, they showed a delayed bud break and bloom and an earlier growth slackening. During the 2008 vintage, limited nitrogen supply was related to early vegetative growth cessation and higher sugars accumulation. It was the not the case of the previous vintage. Environmental stress enhances grape quality, as far as the stress intensity is not too high, which it has probably be the case in 2007. Our results confirm the positive impact of a mild nitrogen deficiency on grape quality obtained in others study (Choné *et al.* (2001); Tregoat *et al.* (2002)). During a mild nitrogen deficiency, berry weight decreases and a higher concentration of favourable compounds in the berry is obtained. On contrary, as it has been demonstrated by Peyrot des Gachons *et al.* (2005), a severe nitrogen deficiency is detrimental to the aroma potential of Sauvignon blanc grapes. In the 2007 vintage, where the grapes nitrogen status was very low, we observed a strong link between low YAN in must and marquee astringency in wines (significant at 1‰). For the 2008 vintage with generally higher nitrogen level in must, the correlation was not significant anymore. In our study, vines located on the terroir "bottom moraines" showed consistently low nitrogen content and the quality of their wines tended to be depreciated.

Conclusion

The aim of this study was to evaluate the influence of terroir on vine behaviour and wine quality. The terroir effect on vine development and wine quality can be explained in large part by the influence of soil type (soil compactness and rooting depth) on vine nitrogen level. Thus, our study confirms the role of nitrogen supply in grape and wine quality and underline nitrogen as a key factor in understanding the terroir effect.

Ackowledgments

Special acknowledgments go to G. Nicol for winemaking and supplying data about sensory analysis.

References

AERNY J., Composés azotes des moûts et des vins. Revue suisse Vitic., Arboric., Hortic. 28: 161:165 (1996)

BUTSKE C., Survey of Yeast Assimilable Nitrogen Status in Musts from California, Oregon, and Washington. Am. J. Enol. Vitic. 49:220-224 (1998).

CHONE X. *et al.,* Terroir influence on water status and nitrogen status of non irrigated Cabernet-Sauvignon (Vitis vinifera). Vegetative development, must and wine composition (example of a Médoc top estate vineyard, Saint Julien area, Bordeaux). S. Afr. J. Enol. Vitic. 22: 8-15 (2001).

GAUDILLERE J. P. *et al.*, Carbon isotope composition of sugars in grapevine, an integrated indicator of vineyard water status. J. Exp. Bot. 53:757-763 (2002)

KELLER M. *et al.*, Nitrogen and water management strategies for wine-grape quality. Acta Hort. 640: 61–67 (2005).

LETESSIER I. *et al.,* Etude des terroirs viticoles vaudois, Géopédologie. Rapport SIGALES, études de sols et de terroirs, 38410 St Martin d'Uriage (France) (2004)

PEYROT DES GACHONS C. *et al.*, Influence of water and nitrogen deficit on fruit ripening and aroma potential of Vitis vinifera L cv Sauvignon blanc in field conditions. J. Sci. Food Agric. 85:73-85 (2005).

TREGOAT O. *et al.*, The assessment of vine water and nitrogen uptake conditions by means of physiological indicators. Influence on vine development and berry potential. J. Int. Sci. Vigne Vin 35:133-142 (2002).

SMART R. E. *et al.*, Canopy microclimate implications for nitrogen effects on yield and quality. Proc. Intl. Symposium on Nitrogen in Grapes and Wine, Seattle, 90–101 (1991)

SPAYD S. E *et al.*, Nitrogen fertilization of White Riesling grapes in Washington. Must and wine composition. Am. J. Enol. Vitic. 45:34-42 (1994).

VAN LEEUWEN C. *et al.*, Influence of climate, soil and cultivars on terroir. J. Int. Sci. Vigne Vin 55:207-217 (2004).

ZUFFEREY V. *et al.*, Assessment of plant hydraulics in grapevine on various terroirs in the canton of Vaud (Switzerland). J. Int. Sci. Vigne Vin 41:95-102 (2007).